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ABSTRACT

Reviewed in this report is a study concerned with water pollution as it relates to urbanization within the Regional Plan Association's set of 21 contiguous New York, New Jersey and Connecticut counties centered upon the numerous bay and estuarial reaches of the Port of New York and New Jersey. With a time frame covering a decade of water quality and pollution data, an attempt was made to devise projections for the next 15 years which might reveal how the urbanization process and the pollution process interact in the region. To implement this task, several stages of research were necessary, as described in the text: (1) development of a hydrologic data bank, (2) screening the data, (3) development of a projection model to estimate the impact on water of effluents associated with industrial growth and population growth, (4) construction of a computer model to simulate the behavior of a river system under the impact of urbanization, and (5) changing the model's premises in accordance with different sets of assumptions and regional growth policies to cast light on how best to alleviate pollution effects. This report concludes a two-part study, the first part of which was published under the title "Benefits From Integrated Water Management in Urban Areas--The Case of the New York Metropolitan Region." (BL)

URBANIZATION, WATER POLLUTION, AND PUBLIC POLICY

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This monograph is the final report in fulfillment of research grant Number 14-31-0001-3147 to Barnard College of Columbia University provided by the United States Department of the Interior, Office of Water Resources Research for a project entitled: "Coordinated Management and Design of Metropolitan Area Water Supply and Waste Disposal Networks -- A Linked Systems Analysis." The authors would like to express their deep appreciation to the Office and its staff for the opportunity to conduct the study upon which this publication is based.

PREFACE

In every sense of the word, this project was a joint undertaking from its inception. Although there was an allocation of principal areas of responsibility, all project members became involved in all major concerns. For the record, however, these are the chief roles which we played:

> George W. Carey -- statistical advisor, mathematical modeling, collation, editing and preparation of the final manuscript.
>
> Leonard Zobler -- overall administrator of the project, hydrological data gathering and analysis.
>
> Michael Greenberg -- population projection, effluent projection, mathematical modeling.
>
> Robert Hordon -- hydrological data gathering and analysis, supervision of the data bank.
>
> Niels West -- acquisition and analysis of data relating to estuarial water quality.
>
> Rae Zimmerman -- preparation of estimates of industrial effluent coefficients.
>
> Steven Frakt -- data gathering, analysis of patterns of pollution ordinance violation and enforcement.

In the final manuscript, each section of our study was basically written by that person whose corresponding area of responsibility is set forth above. The whole was then edited for publication.

The sheer mass of material with which we dealt made it difficult to pare this report down to manageable size. Statistical or cartographic material bearing on only a narrow portion of our study region has been omitted in the interest of maintaining an overall perspective. For example, the detailed analysis of Connecticut water sources from the standpoint of water quality has been left out. We are, however, preparing mimeographed material under the title: Statistical Supplement to Urbanization, Water Pollution and Public Policy. This will be about 50 mimeographed pages, and will be available from:

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In thanking those who played an important part in the fulfillment of our task, we wish to remind the reader that we accept the responsibility for such deficiences in the study which may emerge.

In the colossal task of collecting the data, Toby E. Berger and Garrett A. Smith, Jr., both of Barnard College stand out for their enterprise and dedication. Mr. Smith, in addition, prepared our cartographic material and Miss Berger assisted with data processing. Also engaged in data collection were: Enid Scott, Greg Warren, Debbie Swiderski, Vincente Mas, Robert Holst, Melvin Parker and Colin Webster. Truman F. Peebles was helpful not only in the collection of data, but also for his assistance in data processing.

In the area of programming and machine processing we have to thank our old friend and associate from previous projects, Richard Mautner, who comes close to being the computer consultant par excellence. Barry Appelman of Columbia University was responsible for much program modification and program writing -- especially in the area of population and effluent projections. His help was indispensable in key areas of our undertakings. Goldie Jadczak and Eileen Scardino did most of our card punching.

We are grateful for the advice and counsel on the chemical aspects of water pollution provided by Prof. Samuel D. Faust of Rutgers University and Peter W. Anderson of the U.S. Geological Survey and Rutgers.

Valuable help and guidance was given by Prof. Gerald Palevsky of City University of New York, School of Engineering, our Sanitary Engineering Consultant, who contributed freely and frequently to our staff meetings.

Mr. Ethan T. Smith, of the Environmental Protection Administration not only helped us to acquire some of their excellent data, but served freely as a tireless, informed and constructive critic of our work.

The final typing of the manuscript owes much to the dedication of Sophia Berger, Stephanie Ross and Vera Lee. I am grateful for the valuable editorial help rendered by Nina Shoehalter and Virginia Paulus.

To all of these people we give thanks.

Appended to this Preface is a list of Acknowledgments of persons in various public and private agencies who graciously and helpfully threw open their doors to us for data gathering, interviewing and study purposes.

This report concludes a two-part study of the water resources of the New York-New Jersey Metropolitan Region, the first part of which was published under the title, Benefits from Integrated Water Management in Urban Areas -- The Case of the New York Metropolitan Region by the Clearinghouse, U.S. Department of Commerce, Document PB 184019, April, 1969.

The Authors

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INTRODUCTION

An Overview of the Impact of Pollution on New Jersey-New York Water Bodies, and a Summary of Policy Findings.

A. The Impact of Pollution

The American public has had the fact of water pollution called to its attention vigorously -- if not always coherently -- by a virtual media explosion on ecological issues during the last few years. The emphasis in public discussion has generally been global in scope -- will the earth become uninhabitable for man? -- and heroic in time scale -- will man render himself extinct in the next hundred (or five hundred, or fifty) years?

Our study is neither global nor epochal. It is concerned with water pollution as it relates to urbanization within the Regional Plan Association's set of 21 contiguous New York, New Jersey and Connecticut counties centered upon the numerous bay and estuarial reaches of the Port of New York and New Jersey. Its time frame reaches back over a decade of water quality and pollution data. Our concern was to devise projections -- not for the next 50 years, but rather for the next 15 -- which might reveal how the urbanization process and the pollution process interact in our region.

Given an understanding of these interactions, we might then seek to recommend measures to bring the process under control, and also to evaluate the potential impact of present or pending legislation upon regional growth and development of policy goals.

B. Research Goals

To implement this task, several stages of research were necessary:

1. Development of a data bank;

2. Screening of the data in order to gain an understanding of the most important dimensions of the pollution problem available for analysis, and to eliminate from our consideration those data which were unreliable, irrelevant, or both;

3. Development of a projection model to estimate the impact on water of (a) effluents associated with industrial growth and (b) effluents associated with population growth (such as storm runoff and sanitary sewage);

4. Construction of a computer model, based on the findings above, which would simulate the behavior of a river system under the impact of urbanization;

5. Changing the model's premises in accordance with different sets of assumptions regarding technological improvements in effluent treatment, and regional growth policy in order to cast light upon how best to alleviate pollution effects.

Each of these goals was realized, with varying degrees of success. This report presents one or more chapters on each. But the extent to which any mathematical model accurately reflects reality depends, in the last analysis, upon the quality of the data upon which it is calibrated. After collecting and screening more than one million elements of information in fulfillment of our first goal, and scrutinizing their overall quality, we feel that a gap exists between the information available and the policy demands which pivot on it.

Certain data are reliable enough and well enough structured to call sharply into question existing public orientations and policies with respect to the control of water pollution. These data, however, do not provide a sufficiently rigorous framework with which to examine alternative policies and to decide among them unequivocally.

C. Summary of Findings

Our findings lead us to wonder whether the most challenging task for planners in our region may not be the rational planning of a retreat from urban development in ecologically-stressed areas.

1. The Data Bank

Any data bank has three basic parameters which relate to its usefulness: (a) the variables measured; (b) the frequency of measurement, and (c) the location of measuring points. We find that data on regional water quality are generally inadequate by all three parameters.

-- Lack of coordination due to political and jurisdictional fragmentation, combined with bureaucratic competition.

-- The variables upon which data are collected are sometimes determined by custom dating from the nineteenth century (coliform bacteria), sometimes by crisis-inspired panic (phosphates), sometimes by what the instrument salesman has in his inventory of available instrumentation -- but rarely by the fruits of sound research into a theory of water pollution.

-- The sampling locations are often apparently determined by convenience (where one's car may be parked). In some cases, locations are actually unknown to agency supervisory personnel.

-- Frequency of sampling is often based on convenience. Data records reveal that samples are usually not taken on weekends, holidays or at night. Indeed, they are sometimes skipped during inclement weather as a matter of course.

-- Sensing instruments -- representing an investment of thousands of dollars -- are often allowed to function improperly calibrated for protracted periods of time, occasionally invalidating whole years of data.

-- Where data are conscientiously collected, storage procedures often make their retrieval and use extremely difficult for the researcher.

All of these considerations are documented in the chapter dealing with the data base, and lead us to observe that only in two drainage basins in the

21 county region were data available which proved helpful to us in constructing our model. It is interesting to note that private water companies (with a vested economic interest in clean water) seemed to have the most reliable information, while sewage treatment plants (even when publicly owned, and required to provide data by law) tended to provide the worst information.

The state of water data in the region leads us to recommend guidelines for the establishment of a rational regional quality monitoring network at the conclusion of Chapter I.

2. The Screening of the Data

After identifying the few sets of hard, reliable data within the overall matrix of soft, ill-designed data, we examined them for the purposes of simulation. By factor analysis, we found that the most significant and meaningful aspects of the pollution problem revealed in the material available lay along three statistically separate dimensions: the status of dissolved oxygen (DO) in the stream in relation to biochemical oxygen demand (BOD) -- a measure of organic pollution; the appearance of the stream in relation to discharge, color and turbidity; and the percent of oxygen saturation in the stream's water.

-- DO Status. The DO level of a stream varies inversely with water temperature and BOD. Cold, clean streams have higher DO levels than warm, polluted ones. By extension, pollution levels are most critical in the summer.

-- Appearance. Urbanizing watersheds create dust and dirt, which wash into streams when rainfall occurs and the stream rises. The appearance of the stream (muddy, dirty looking) is not necessarily related to the quality of the water (as measured by oxygen content). Clean looking water can be highly polluted.

-- Percent saturation. The amount of oxygen in a stream in comparison to the amount which water at its temperature can possibly hold -- generally shows statistically less sensitivity to BOD levels than does the overall DO level of the stream.

The structure of environmental data surveillance efforts generally bears little relationship to the operation and management of the region's water resource system.

The technology of chlorination is pivotal to all water management efforts. This makes the region doubly vulnerable.

a. Should the increasing use of chlorine produce damaging side-effects affecting humans, water supply-pollution control efforts would be thrown into chaos.

b. A new generation of pollutants -- persistent toxic metals, synthetic organics and resistant pathogenic viruses -- now threaten us, and cannot be controlled by chlorine. <u>Yet, owing to our reliance on chlorine as a panacea, we have neglected to establish a</u>

regional data surveillance network which might aim to control these pollutants by enforcement.

-- Massive effluents discharged by huge regional plants into the ocean from groundwater-dependent areas like Long Island have the effect of lowering water tables so as to threaten groundwater supplies with salt water intrusion and contamination. There is no strategy of dispersed, high level technological plants equipped for controlled and monitored inland infiltration and reinjection.

-- The estuarial waters, which are the hydrological sinks to which waters flow, exhibit DO gradient patterns which reveal the cumulative impact of land-originated pollution.

-- Our findings challenge the notion that because the highly-polluted Arthur Kill discharges around the north shore of Staten Island, it does not greatly affect the Raritan Estuary. On the contrary, our evidence suggests a noticeable flow from the Arthur Kill into the Raritan Estuary. This implies that planning for the Newark Bay-Kills-Hudson River estuarial region cannot logically be disassociated from planning for the Raritan area.

-- Observable Nitrate and Phosphate pollution exist in the estuary.

These considerations which arose from a variety of data sources led us to consider the DO in the stream as the most important variable measuring water quality which was available and amenable to simulation.

Not only did DO appear as the most significant variable in terms of statistical explanation for all stations and basins for which the data were available, but the fortunate reinforcement of the Elizabethtown Water Company data by the Federal Environmental Protection Administration data gave us the opportunity to develop a comprehensive simulation model for 38 stations on the Raritan and its major tributaries.

3. Projection of Urbanization Effects Upon Water Quality

The data available on industrial effluent and treatment plant effluent were the most inadequate data which we acquired. This section of our project was, in effect, a search for indirect means of estimating effluents through the use of surrogate variables.

-- One measure of urbanization is the percent of an area covered by impermeable surfaces. We discovered that storm sewer runoff, and certain concomitants of dense population growth, such as illegal dumping could be estimated from this variable.

-- By developing a series of technological coefficients at the four-digit S.I.C. level* for plants having a given level of modernity, we estimated potential effluents for 2,026 industrial plants.

*Federal statistics are often compiled for industry by reference to the Standard Industrial Code (S.I.C.). The first two digits of a four digit coding refer to broad categories of industry (i.e. chemical). The second pair refer to fine distinctions within the broad category (i.e. paints and varnishes).

-- Domestic sewage may be estimated through population projections at the level of minor civil divisions. For 567 minor civil divisions in 200 sewer service areas, we devised a computer program to project population growth, and thence effluents through 1985 based on estimated per-capita influent coefficients, as well as treatment plant size, location and technology.

4. The Simulation Model

Since DO responds to water temperature and BOD, and since water temperature responds to changes in climate over the year, our DO stimulator is based on fitting DO to the time of year by means of harmonic analysis. The coefficients of the harmonic analysis equations, in turn, are estimated from the pollution figures developed in 3. above, along with various stream parameters.

-- The model is fitted and successfully calibrated to 38 stream-monitoring stations on the Raritan River and its major tributaries and backfitted to 1969-70 data.

-- The model successfully duplicates DO characteristics for all stations, to the extent that the simulated DO fits the measured DO yielding a statistical explanation as low as 62% in only one case, and near 90% for most of the others.

5. Policy Implications of the Model

Our model is arranged so that a variety of assumptions regarding the extent of urbanization, the degree of technical control of the effluents, the distribution of waste treatment facilities, the degree of population growth, and the transmission of upstream pollution loads to downstream points may be tried out in order to ascertain their impact on the DO levels in the river system. Our findings for a river system patterned after the Raritan are as follows.

-- While existing practice dictates large sewage treatment plants located at downstream points in river basins, we question this policy from an environmental, an economic, and a planning perspective.

a. Environmental. The immense upstream assimilative capacity of the stream goes unused since upstream suburban areas are kept pristine at the expense of downstream urban areas.

b. Economic. The apparently favorable cost-benefit picture of the large regional plant is based upon public policies which underwrite capital construction costs in order to reduce the labor and maintenance costs. A small plant network strategy would provide more jobs and more social benefits arising from the better utilization of stream assimilative capacity. It would shift the goals of optimization away from traditional public finance-oriented goals towards ecological ones.

c. Planning. The failure of one large regional plant under conditions of stress will be more serious than the failure of one smaller plant which is part of a basinwide network. Furthermore, an efficiently designed network presents the opportunity for treatment capacity tradeoffs if one portion of the network is stressed at a given time.

-- Large regional treatment plants -- even though highly efficient by present technical standards -- will exacerbate pollution problems in portions of the basin.

-- Present water quality standards cannot be met in all reaches of the basin -- even if effluent standards are rigorously enforced -- unless regional development in <u>both</u> population and industrial growth is not only restricted, but reversed so as to diminish both industrial activity and population density.

Our study of pollution suggests that the traditional commitment of our society to continued economic growth (as in the case of the Raritan Basin) has produced its own antithetical need to limit and even to reverse growth lest the cumulative ecological deterioration of our environment proceed to a level where dangerous and irreversible damage is done.

PART ONE: The Present State of the Regional Hydrological System

The next five chapters present a picture of the state of river, estuarial and groundwaters in the New Jersey-New York Metropolitan Region, gleaned from an exhaustive analysis of existing data. Chapter I describes the regional data bank which we have amassed in great detail. The reader interested only in the policy recommendations flowing from our study of the data resources of the region should skip to page 55 which presents our design for improving data surveillance.

Chapters II, III, and IV present detailed technical analyses of riverine, estuarial and groundwater data relating to water quality and the impact of pollutants. The reader interested only in the gist of this material and the principal findings should read pages 65-67 in Chapter II, and then skip to Chapter V, which should be read in its entirety, since it reviews the substance of the three technical chapters.

CHAPTER I

THE HYDROLOGIC DATA BASE

One of the major objectives of this research project was to assemble a water quality data bank for the New York Metropolitan Region (NYMR), from the historic record. Following this, the spatial and temporal variations and covariations in the behavior of the water quality variables are examined. No raw data were collected; rather, we relied on information gathered by field agencies and made available to us.

As it turned out, a disproportionate share of our research endeavors had to be allocated to the compilation of a data bank. The obstacles in our path were many -- data unavailability, poorly kept records, parameter and temporal discontinuities, and, regrettably, several instances of noncooperation and withholding of information. The surmounting of these barriers proved to be a frustrating and only partially successful experience.

At present, there is no single centralized agency for the NYMR which supervises data collection, storage and retrieval for all of the information in a common format that reflects changes in the natural and man-altered water bodies and their hydrologic connectivities. Our research group had, in effect, to assume the dimensions of such an agency merely to satisfy our goals, even though we were obviously understaffed for such a task. Because the deficiencies in the data bank threatened the attainment of our objectives, a critique of the existing information system is mandatory. The objective of this chapter is to describe the distribution of the sampling stations in the region, the nature of the variables sampled, the sampling periodicities, and the agencies that performed the sampling. Commentary also is made from the user's point of view about access to information. Finally, suggestions are offered for improving present arrangements.

The organization and operation of the agencies responsible for collecting water quality data reflect the institutional history, hydrography and political geography of the NYMR, a 21-county area covering three states -- New Jersey, New York, and Connecticut. Given the prevailing confusion over authority, jurisdiction, and procedure, we follow in this chapter a simple and direct approach to cut through the morass of detail. We disaggregate the data by states, except for the estuary and, then, proceed to examine the intrastate operations. In the final section of this chapter, in which we recommend changes, this approach is dropped in favor of an analysis built around the functional water institutions responsible for safeguarding the regional water system.

A. New Jersey

In the New Jersey part of the NYMR, seven major public and private agencies have collected water quality and flow information on water sources, receiving bodies of water, and spent water discharges. This information is divisible into data subsets that describe quantity and quality parameter variations, observation frequencies, length of record, and sampling locations. The utility of these data for intra- and inter-basin analysis to provide the bases for water policy formation depends on their consistency, congruence, and laboratory and bookkeeping reliabilities. On all counts, as the following discussion will show, performance has been disappointing. Figures 1, 2, 3, show the location of the sampling paints by stream basins.

1. Intrabasin Inconsistencies

Difficulties arise even with intrabasin comparisons among the variables collected by one agency. For example, the Elizabethtown Water Company (EWC) collects 6, 9 and 17 variables daily, weekly, and monthly. Yet, as shown in Table 1, only 5 variables (temperature, pH, turbidity, color, and alkalinity) are common to all three sampling frequencies. Worse yet, our analyses showed that turbidity and color and, possibly, pH and alkalinity are strongly associated variables; so the five common variables reduce to three sets.

Another example of single-agency intrabasin inconsistencies is provided by the Passaic Valley Water Commission (PVWC). Out of the 16 variables collected by the agency, only nine are common to all of the sampling locations over a ten-year record (see Table 2, page 15). Even with the nine variables, frequencies vary from semimonthly to monthly from station to station from year to year. Thus, problems of analysis and interpretation develop within data sets judged to be reliable and of high quality.

The data set collected by the federal Environmental Protection Agency (EPA) as part of the Raritan Basin Project is one of the best in the region. In terms of number of variables (16), number of sampling locations (40), and frequency (biweekly), the EPA set is clearly an excellent addition to the data bank of the region. Yet, out of the 18-month sampling period selected by EPA for analysis (2/69-9/70), the record was missing for July of 1969 and 1970, and for the winter months of mid-December 1969 to mid-February 1970. Missing records pose obvious difficulties, particularly when one wishes to use time series analysis.

2. Operations of Data-Collecting Agencies

a. Water Supply Companies

Public potable water supply systems have an obvious interest in water quality since their treatment costs rise rapidly with the deterioration of water quality (Fuchs, 1968). The Elizabethtown Water Company (EWC) is one of the largest private potable water distributors in the United States. EWC supplied an annual average flow of 117 mgd in 1971 to 44 municipalities in central New Jersey (EWC Annual Report, 1971). Most of the water (about 75%) is diverted from the Raritan and Millstone Rivers and the Delaware-Raritan Canal near Bound Brook.

As shown in Table 1, EWC samples its raw water on a daily, weekly and monthly basis for 6, 9 and 17 variables, respectively, for each of the three intakes. The information is recorded on lab sheets. As far as is known, no attempt has been made by EWC to keypunch this information for data processing.

As shown in Table 4, our EWC data bank contains over 37,000 bits of information, consisting of the daily records for 1960 and 1969, and the weekly and monthly records for the decade 1960-69. With the addition of discharge and percent saturation, the best mix of frequency of observation and total number of variables is attained with the weekly series. A statistical analysis of the data is provided in the next chapter.

FIGURE 1.

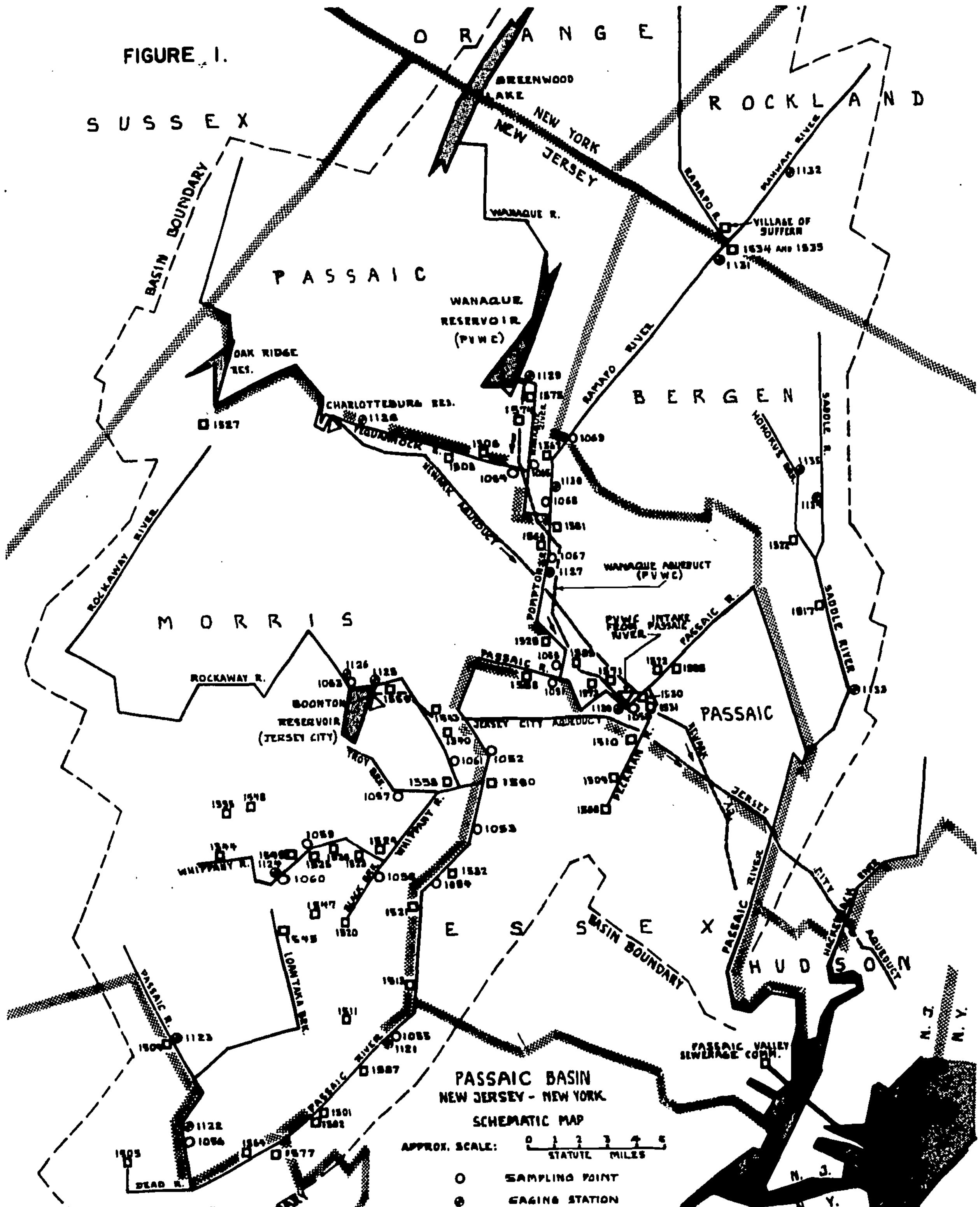

ORANGE
ROCKLAND
SUSSEX
PASSAIC
BERGEN
MORRIS
PASSAIC
ESSEX
HUDSON
SOMERSET
GREENWOOD LAKE
NEW YORK
NEW JERSEY
WANAQUE R.
WANAQUE RESERVOIR (PVWC)
OAK RIDGE RES.
CHARLOTTEBURG RES.
RAMAPO R.
MAHWAH RIVER
VILLAGE OF SUFFERN
RAMAPO RIVER
BASIN BOUNDARY
ROCKAWAY RIVER
ROCKAWAY R.
BOONTON RESERVOIR (JERSEY CITY)
WANAQUE AQUEDUCT (PVWC)
PVWC INTAKE FROM PASSAIC RIVER
PASSAIC R.
JERSEY CITY AQUEDUCT
SADDLE RIVER
WHIPPANY R.
PASSAIC RIVER
DEAD R.
PASSAIC VALLEY SEWERAGE COMM.
N. J.
N. Y.
PASSAIC BASIN
NEW JERSEY - NEW YORK
SCHEMATIC MAP
APPROX. SCALE:
STATUTE MILES
SAMPLING POINT
GAGING STATION
SEWAGE TRT. PLANT
INTAKE FOR WATER SUPPLY
COUNTY BOUNDARIES
G. SMITH 1972

FIGURE 2.

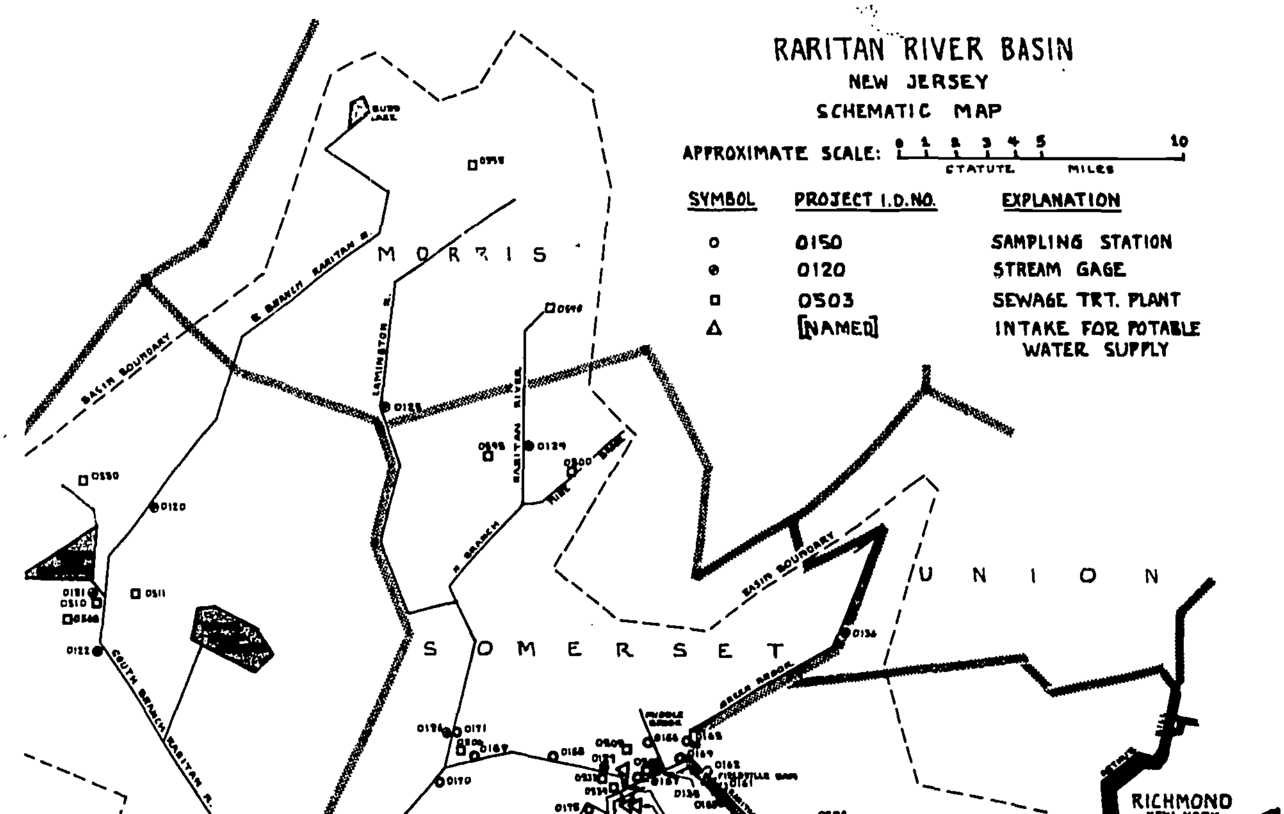
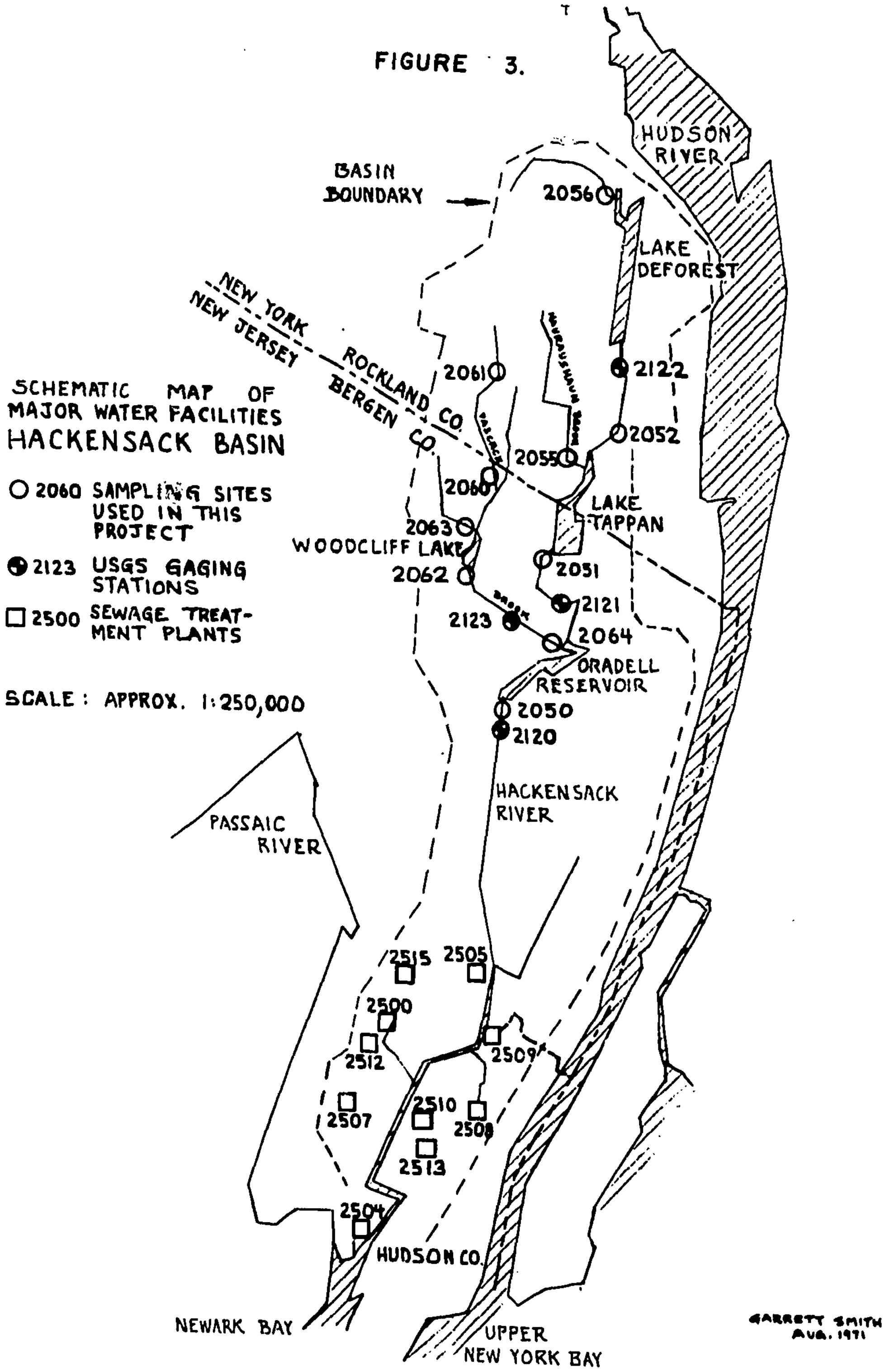

RARITAN RIVER BASIN
NEW JERSEY
SCHEMATIC MAP
APPROXIMATE SCALE: 0 1 2 3 4 5 10
STATUTE MILES
SYMBOL
PROJECT I.D.NO.
EXPLANATION
0150
SAMPLING STATION
0120
STREAM GAGE
0503
SEWAGE TRT. PLANT
[NAMED]
INTAKE FOR POTABLE WATER SUPPLY
MORRIS
SOMERSET
UNION
HUNTERDON
MIDDLESEX
MERCER
MONMOUTH
RICHMOND
NEW YORK
BASIN BOUNDARY
SOUTH BRANCH RARITAN R.
LAMINGTON R.
RARITAN RIVER
MILLSTONE RIVER
GREEN BROOK
N.J.
PA.

FIGURE 3.



REV. 1

Table 1. Elizabethtown Water Company - Sampling of Raw Water at the Raritan, Millstone, and the Delaware-Raritan Canal Intakes, 1960-69

Variable		Daily	Weekly	Monthly
1.	Water Temperature	X	X	X
2.	pH	X	X	X
3.	Turbidity	X	X	X
4.	Color	X	X	X
5.	Alkalinity	X	X	X
6.	DO	-	X	X
7.	Hardness	-	X	X
8.	Bacteria	X	X	-
9.	BOD		X	-
10.	Iron			X
11.	Manganese			X
12.	Consumed Oxygen			X
13.	Chlorides			X
14.	Organic and Volatile			X
15.	Total Solids			X
16.	Mineral Matter			X
17.	Albuminoid Ammonia			X
18.	Calcium			X
19.	Magnesium			X
	TOTAL	6	9	17

The Passaic Valley Water Commission (PVWC) distributes water directly to 300,000 people living in Paterson, Passaic, Prospect Park and a part of Clifton, PVWC also sells water in bulk to as many as 12 separate water supply agencies (Zobler, Carey, Greenberg and Hordon, 1969). PVWC is a public agency which has diversion rights of 75 mgd from the Passaic River at Little Falls whenever the flow is sufficient (Durfor and Becker, 1965).

The Little Falls intake is only a few miles upstream of the tidal portion of the Passaic. As such, it occupies the most downstream portion of an upland river which receives an enormous volume of effluent relative to stream flow. Lesser, Spinner, and Tirabassi (1970) estimate that 117 sewage treatment plants discharge their partially-treated effluent into the Passaic basin above Little Falls. Consequently, PVWC is extremely conscious of water quality conditions and has gone to court to suspend the operations of particular offenders.

As part of a voluntary stream surveillance program, PVWC maintains a sampling network of 19 stations throughout the basin, 13 of which have records going back to at least 1960. The sampling frequency is monthly, but biweekly samples were occasionally collected in the early 1960s.

The number of variables sampled ranges from a common set of nine to occasional complete sets of 16, as shown in Table 2. The variable set shows a definite increase during the late 1960s. Our PVWC data bank consists of nearly 32,000 bits of information.

The third major water supply agency in New Jersey with an active program in water quality sampling is the Hackensack Water Company. Together with its subsidiary in Rockland County, New York (the Spring Valley Water Company), it serves a population of nearly 1,000,000 in a 260-square-mile territory consisting of over 70 municipalities. The combined average annual daily production of water in 1971 was 110 mgd (Hackensack Annual Report, 1971).

The company maintains a network of ten stream sampling sites in the Hackensack River basin in both New Jersey and New York, as shown by Figure 3 . The sampling frequency is weekly, but gaps exist in the record. The number of variables sampled ranges from nine to sixteen, as shown in Table 2. Our data bank for the Hackensack includes the period 1960-69, yielding a useful total of over 38,000 bits of information (see Table 4, page 18).

The New York State Department of Health maintains one water sampling station on the Hackensack River in Rockland County, N.Y. We have evaluated the congruence of that record and the data of the Hackensack Water Company in the same area. In our judgment the effort of extracting the record from tapes provided by the Department of Environmental Conservation would not have expanded our data bank significantly.

b. Government Regulatory and Scientific Agencies

The Edison, New Jersey, unit of the Water Quality Office of the U.S. Environmental Protection Agency (EPA) instituted a comprehensive survey of the Raritan River basin in 1969 (Morris, 1969). This Raritan Basin Project

Table 2. Passaic Valley Water Commission (PVWC) and Hackensack Water Company (HWC) - Sampling of Raw Water, 1960-69

Variable	PVWC[a]	HWC[b]
	[c]	[c]
1. Water Temperature	XX	XX
2. pH	XX	XX
3. Turbidity	XX	X
4. Color	XX	XX
5. Alkalinity	XX	X
6. DO	XX	XX
7. Hardness	X	-
8. Bacteria	X	X
9. BOD	XX	X
10. Iron	-	X
11. Manganese	-	X
12. Consumed Oxygen	-	X
13. Chlorides	XX	XX
14. Percent Saturation	XX	XX
15. Coliform	X	XX
16. CO2	X	-
17. NH3	X	-
18. NO2	X	X
19. NO3	X	X
TOTAL	16	16

[a] PVWC maintains 19 sampling sites in the Passaic Basin, 13 of which have records going back to at least 1960. The sampling frequency is monthly, and for some stations, semimonthly.

[b] HWC maintains 10 sampling sites in the Hackensack Basin with some stations visited weekly.

[c] Those variables which are common to all stations throughout the decade 1960-69 are denoted by "XX".

was to be modeled after the Delaware Estuary Comprehensive Survey (U.S., FWPCA, 1966), and a mathematical model of the basin was to be formulated as part of a plan to control and abate pollution through 1990.

The data base for the EPA project is impressive -- a network of 40 stations sampling 16 water quality variables throughout the Raritan Basin on a biweekly basis was begun in February of 1969 (see Table 3, page 17). The sampling program was maintained for 18 months, resulting in 29,000 bits of information. Although the record has gaps, the EPA program represents one of the best stream surveys in New Jersey

The EPA data were punched and stored in the STORET system -- a comprehensive data storage and retrieval system developed by federal pollution control personnel during the 1960s (Dubois, 1966). Water quality variables are identified by a unique five-digit parameter number. Code numbers exist for 839 possible parameters (U.S., FWPCA, STORET, 1970), a number vastly greater than the usual assortment of available variables.

A serious problem arose in the utilization of the STORET system. One cannot use the wide variety of statistical routines available in standard library routines without an expensive reformatting procedure. One solution to the format problem is to retrieve specific data from the STORET system in the form of a computer printout, then punch the data in a fixed field format. Another solution is to write a computer program that will convert the STORET format to another format. Our project employed both and found that both are expensive or time-consuming.

It is interesting to note that other researchers -- such as those involved in the Water Resources Research Institute at Rutgers University -- have also encountered STORET retrieval problems. Generally, they adopted the first method -- the acquisition of printout and the punching of new cards (General William Whipple, Jr., Director, Water Resources Center, Rutgers University, New Brunswick, N.J., personal interview).

The U.S. Geological Survey (USGS) has sampled chemical quality, suspended sediment and water temperatures at various sites in New Jersey since 1941 (USGS, 1970). The sampling frequency is monthly, except for certain stations where daily readings are obtained of selected variables. As indicated in Table 3, as many as 24 variables are sampled, although there are usually gaps in the record.

The increasing interest in environmental quality is reflected in the expanding number of stations in New Jersey where chemical quality is sampled, as follows: 1962 - 22, 1964 - 29, 1966 - 36, 1968 - 37, 1970 - 42 (USGS, 1964, 1966, 1968, 1970).

The USGS has been active in the use of electronic monitors as a supplement to manual sampling. However, the robots are susceptible to sensor malfunctions. For example, the monitor on the Millstone River at Manville recorded only 141 daily readings of dissolved oxygen (DO), or 39% of the water year ending September 1970. The monitor on the Pompton River at Two Bridges was only slightly better: 152 daily readings of DO. or 42% of the total number of days in the year.

Table 3. Government Agencies - Sampling of Raw Water

Variable	EPA[a]	USGS[b]	State of N.J.[c]
	[d]		
1. Water Temperature	XX	X	-
2. pH	XX	X	X
3. Turbidity	XX	-	X
4. Color	-	X	X
5. Alkalinity	XX	X	-
6. DO	XX	X	X
7. Hardness	-	-	-
8. Bacteria	-	-	X
9. BOD	XX	X	X
10. Iron	-	X	-
11. Manganese	-	X	-
12. Chlorides	XX	X	-
13. Coliform	XX	X	-
14. Fecal Coliform	XX	-	-
15. NH3	XX	-	X
16. NO2 (Nitrite)	X	-	-
17. NO3 (Nitrate)	XX	X	-
18. Phosphate	XX	X	X
19. Air Temperature	XX	-	-
20. Conductivity	XX	X	-
21. Organic Nitrogen	XX	-	-
22. Suspended Solids	-	-	X
23. Silica		X	
24. Sodium (Na)		X	
25. Potassium (K)		X	
26. Na + K		X	
27. Bicarbonate (HCO3)		X	
28. Carbonate (CO3)		X	
29. Sulphate (SO4)		X	
30. Fluoride		X	
31. Dissolved Solids		X	
32. Calcium		X	
33. Magnesium		X	
TOTAL	16	24	9

[a] U.S. Environmental Protection Agency, Edison, N.J. (Raritan Basin Project, 2/69 - 9/70).

[b] U.S. Geological Survey.

[c] Department of Environmental Protection, State of N.J., 1964-69.

[d] Those variables which are common to all stations during the period in question are denoted by "XX".

Table 4. Water Quality Data Bank for Northeastern New Jersey

Agency	Bits of Information
Elizabethtown Water Company	37,173
Passaic Valley Water Commission	31,096
Hackensack Water Company	38,033
Environmental Protection Agency	29,348
U.S. Geological Survey	3,960
State of N.J. - Streams	18,120
State of N.J. - Sewage Treatment Plants	56,000
Middlesex Co. Sewerage Authority	4,000
TOTAL	217,730

The State of New Jersey collects surface water samples at over 200 stations on a quarterly basis. The collection and analysis were originally performed by the State Department of Health, but this function has been transferred to the recently created Department of Environmental Protection.

The number of variables sampled averages about nine, as indicated in Table 3. The sampling stations by basin are as follows:

Raritan	70
Delaware-Walkill	57
Atlantic Coastal Plain	33
Passaic	30
Hackensack	8
Rahway-Elizabeth	4
	202

Louis M. Spiro of the Rutgers Geography Department has studied the records of the 70 sampling stations on the Raritan. He finds the data for 32 (46%) of the stations to be so irregular that they are of very limited value for analysis. For example, one station on a tributary in Washington Township had only nine measurements instead of the expected 20 during the period 1966-70. Even if the quarterly sampling had been conducted correctly, its infrequency makes it too crude a yardstick for the measurement of water qual .y. Moreover, not only was the quarterly sampling insufficient, but it was not even taken at consistent three-month intervals. Instead, many measurements were taken in March, followed by more in April, and then the next ones were not taken until September. Obviously, this inconsistency further reduced the value of the data (Spiro, 1970).

c. Groundwater Data in Northeastern New Jersey

The Atlantic Coastal Plain Province underlies all of Monmouth and eastern Middlesex Counties in northeastern New Jersey. The unconsolidated rocks of Cretaceous and Cenozoic age include a number of formations which vary in their water-bearing properties. The Coastal Plain formations range in thickness from thin outcrops near the Fall Line to depths greater than 1,200 feet near the shore. Most large public-supply and industrial wells obtain water from the Raritan-Magothy formation of Cretaceous age, similar to the main source of supply in Long Island.

The geohydrologic properties of the Coastal Plain formations favor groundwater development. Consequently, considerable information is available for wells in this geologic province. Moderate quantities of groundwater are available from the fractured shales and sandstones of the Triassic Lowland -- a province underlying most of northeastern New Jersey. Groundwater is also obtained from unconsolidated stratified drift deposits in the glaciated portions of northern New Jersey.

Although information is available on the chemical characteristics of well samples, surveys tend to be of limited frequency. Due to the limited variability of groundwater characteristics as compared to surface water variability, only occasional surveys and annual samplings are available for most wells. Irregularity marks the sampling program, as evidenced in Table 5, page 21.

The U.S. Geological Survey (USGS) is the prime agency for collecting and analyzing groundwater information. Its water quality analysis may include up to 22 variables, as follows:

1.	Silica	12.	Fluoride
2.	Iron	13.	Nitrate
3.	Manganese	14.	Phosphate
4.	Calcium	15.	Dissolved Solids
5.	Magnesium	16.	Hardness
6.	Sodium	17.	Noncarbonate hardness
7.	Potassium	18.	Specific Conductivity
8.	Bicarbonate (HCO3)	19.	pH
9.	Carbonate (CO3)	20.	Color
10.	Sulphate	21.	Temperature
11.	Chloride	22.	Aluminum

The USGS began regular publication of groundwater analyses on a water year basis in New Jersey in 1967 (USGS 1967, 1968, 1969, 1970). The number of wells sampled in each county is indicated in Table 5 .

As Table 5 shows, the coverage from year to year is highly variable; note how the Middlesex County figures range from zero in 1967 and 1968 to 43 in 1969. Also, although not specified in the table, the sampling frequency was only once a year.

In addition to the recent USGS groundwater records, the State of New Jersey has published some basic groundwater information and interpretation under a variety of commissions. Usually, the work was done in cooperation with the USGS. For example, Barksdale and others discussed the groundwater supplies of Middlesex County in a series of special reports (Barksdale, 1937; Barksdale et al., 1943). Special attention was paid to salinity intrusion problems along the Raritan estuary as a consequence of excess pumping. The geology and groundwater supply of the Newark area was discussed by Herpers and Barksdale (1951).

The New Jersey Water Supply Act of 1958 authorized a statewide groundwater investigation program to be carried out in cooperation with the USGS. Generally, the reports covered a specific county.

The continuing encroachment of salt water into the Raritan formation aquifers near Sayreville, Middlesex County was considered by Appel (1958). One of the conclusions of the study was a recommendation for a tidal dam on the South River, a tributary to the tidal portion of the Raritan. Further discussion of the tidal dam and artifical recharge designs was reported upon by the State Division of Water Policy and Supply (1965) and by Hasan, Kasabach, and Malone (1969).

Table 5. Number of Wells Sampled in Selected Counties in New Jersey, 1967-1970[a]

County	1967	1968	1969	1970
Monmouth	-	33	26	4
Middlesex	-	-	43	35
Union	-	6	10	-
Morris	8	2	-	-
Passaic	-	-	11	-
Somerset	-	3	-	-
Hudson	-	-	3	-
Essex	-	1	-	-
TOTAL	8	45	93	39

[a] Water years which run from October 1 to September 30. Thus, the 1967 water year runs from October 1, 1966 to September 30, 1967.

Seaber (1963) reported the chloride concentrations from 1923-61 of some 113 and 119 wells in Middlesex and Monmouth Counties, respectively. Jablonski (1960, 1968) evaluated the relative importance of the aquifers of Monmouth County. The quality of the groundwater in each of the six aquifers was also discussed. Anderson (1968) discussed the geology and groundwater resources of the Rahway area in Union County. The report included a chemical analysis of 34 wells with 18 variables. A similar report was prepared for Essex County by Nichols (1968), including an analysis of 16 wells. The New Jersey Geological Survey prepared a report on the geology and groundwater of parts of Bergen, Morris and Passaic Counties (Widmer, Kasabach, and Nordstrom, 1966).

A series of reports was prepared for Morris County as part of the regular statewide groundwater investigation program and also as a consequence of the 1962-66 draught. Gill and Vecchioli (1965) wrote about the availability of groundwater in Morris County and included an analysis of 51 wells sampled for 19 water quality characteristics. The draught prompted an investigation into the possibility of obtaining additional supplies of groundwater from deposits of sand and gravel of glacio-fluvial origin in the "glacial Lake Passaic" region. The moderately favorable results of the emergency test-drilling program was reported by Vecchioli and Nichols (1966) and by Vecchioli, Nichols and Nemickas (1967).

Summarizing, a variety of groundwater data is available for portions of northeastern New Jersey. The largest amount of information is available for wells in the Coastal Plain counties, as expected. However, many wells are sampled at infrequent intervals, usually once a year to once every several years. Thus, the existing data, while extensive in terms of variables analyzed, are insufficient for a time series analysis.

d. Sewerage Agencies

It is estimated that there are over 700 sewage treatment plants in New Jersey (New Jersey Department of Health, 1969). The operators of these plants are expected to fill out a standardized report every month and send it to the Bureau of Water Pollution Control of the Department of Environmental Protection in Trenton. In addition, the state attempts to obtain quarterly samples of sewage effluent from each plant. The combined list of variables potentially obtainable is impressive, as the following list indicates:

1. Turbidity
2. Flow
3. Raw sewage bypassed
4. Residual chlorine

5. pH
6. DO
7. Number of connections to the plant
8. Number of new connections to the plant

9. Bacteria
10. Suspended solids
11. BOD
12. Color

13. Ammonia
14. Nitrate
15. Phosphate
16. Settleable solids by volume (%)

Unfortunately, the list of variables actually available is much less. Occasionally, one finds several variables recorded on the Monthly Operator's Reports. Of course, this assumes that operators send in their reports -- an assumption which is not borne out by examining the State files in Trenton. At the State office the reports are filed in manila folders which are designed to hold only 24 issues. As a new report comes in, the oldest report is discarded. This method solves the storage problem, but at the cost of the loss of the information contained in the discarded report.

As shown in Table 4, our effluent data bank for the 231 sewage treatment plants in northeastern New Jersey amounts to over 56,000 bits of information. Some of the larger plants maintain excellent records of their operations -- notably, the Bergen County Sewerage Authority, the Middlesex County Sewerage Authority, and the Rahway Valley Sewerage Authority. The records of the Middlesex County Sewerage Authority alone amount to over 4,000 bits of information.

3. Evaluation

An ideal water data bank for a region as large and as hydrologically diverse as the NYMR should possess conformality of data sets, consistency of collection, maintenance of historic records, standardized formats, and representative sampling locations, times, and frequencies.

The nonconformality of the data sets is shown in Tables 1 to 3. The agencies mentioned in the table sample fresh upland streams with the exception of EPA which also sampled the tidal Raritan. Note the variations in the parameters sampled and also in the frequency of sampling. Inter-basin comparisons become particularly difficult.

The routine discarding of information by one agency has been noted. The Bureau of Water Pollution Control of the Department of Environmental Protection of the State of New Jersey collects Monthly Operator's Reports from all of the state's approximately 700 sewage treatment plants. These reports are filed in a central office in Trenton for only two years. As far as is known, no attempt is made to microfilm the older reports, store them in a warehouse, or publish summarized descriptive statistics of the data.*

*For a complete and thoroughly documented study of the administrative aspects of New Jersey's water pollution control program, the reader is referred to Burch, Philip H., Jr., An Analysis of New Jersey's Water Pollution Control Program, Water Resources Research Institute, Rutgers University, November 1970.

The correct frequency of sampling is an unresolved problem. Obviously, it depends upon the objectives of the given survey. Since our data were obtained from different agencies possessing varying objectives, the frequencies observed ranged from daily to quarterly samples. The notion that quarterly sampling can provide a representative value is dubious. On the other hand, some similarities in factor structures among the daily, weekly and monthly samples collected by EWC on the Raritan suggest that for certain analytical purposes, increased frequency does not always yield increased information.

A related problem is the time of sampling. Kittrell (1969, p. 39) notes the importance of diurnal variations in DO resulting from photosynthesis. Yet almost all of the agencies collect their data in the morning. One wonders if the data sets so obtained contain a built-in upward DO bias.

An additional bias in water quality sampling may arise from location. Bridges are favored sites because of accessibility and the fact that a boat is not needed. However, stream channels may be constricted at bridge crossings, resulting in increased velocity and turbulence. This agitation can bias DO values upward. Indeed, at one location on the Millstone River just below Lake Carnegie Dam, the mean DO over an 18-month period was 10.2 ppm, while another site only two miles downstream had a mean DO of 7.6. Part of the disparity can be attributed to the turbulence caused by spill over the dam.

Data bookkeeping and format arrangements for machine processing also present serious analytical difficulties. The analyst is confronted by a plethora of individualized formats because every agency collects information on its own forms. Temperature may be the first, fifth, or tenth variable to be collected, and so on. Over 15 separate formats for the agencies in the NYMR have been identified.

Rational water quality management requires a centralized, computerized and standardized data bank. A single agency should be responsible for coordinating and managing a regional data bank. The data bank manager should routinely collect information gathered by many other agencies. Delay results in lost information. For example, EWC water quality records going back to the 1950s become "lost" or misfiled, and even company personnel have difficulty retrieving the information.

In addition to the major agencies mentioned previously, other agencies maintain or have maintained water sampling programs. For example, the Middlesex County Sewerage Authority (MCSA) supported an extensive program of sampling on the lower Raritan following the creation of the Authority in 1950 (MCSA Annual Report, 1969). Indeed, the MCSA deserves special mention as one of the few sewerage authorities in the state that not only has well organized records but is also willing to release information. Other organizations include the North Jersey District Water Supply Commission and citizen conservation groups, such as the Stony Brook-Millstone Watershed Association and Citizens Against Water Pollution in Monmouth County, New Jersey.

The absence of a state agency that monitors groundwater directly or collects quality information from water companies is striking. When wells first are certified, a sample is taken, but no continuing record is maintained. Companies producing from groundwater sources sample irregularly and maintain their own records. Their interest, and that of the state and county, however, is in the quality of the treated water, not raw water.

Data pertaining to other major components of the hydrologic cycle are satisfactorily recorded. For example, records of streamflow or precipitation may be obtained from the USGS and the National Oceanic and Atmospheric Administration in Asheville, North Carolina, respectively. The need is apparent for an analogous structure to record water quality data. A well organized data bank provides the essential base for water resource and land use planning.

B. Connecticut

Record keeping by water agencies for that part of the NYMR included in Connecticut, Fairfield County, reveals the same shortcomings mentioned in the New Jersey section of this chapter -- variations in parameters, temporal breaks, systematic sampling biases, changes in laboratory methods, and formatting variations. Because of differences in the hydrography of the two areas, however, the import of these incongruences for the water surveillance system is less serious in Connecticut for intrabasin studies than in New Jersey.

Southwestern Connecticut has many small drainage basins, whose streams discharge into Long Island Sound, becoming estuaries in their lower reaches. Settlement patterns and water service areas show adaptations to the natural hydrography formed by the drainage basins of the Byram, Mianus, Rippowan, Noroton, Five Mile, Norwalk, Saugatuck, Mill, Rooster, and Poquonock Rivers. (Their water resources are described in Ryder, et al., part 4, 1970.) To the east is the drainage basin of the Housatonic River, which forms the eastern boundary of Fairfield County.

The stream and groundwater hydrology of the southwestern coastal river basins has been examined recently as part of a general water resources inventory of Connecticut (Ryder, et al., part 4, 1970, and part 5, in preparation). Although much valuable information is contained in these reports it is apparent from examination that they do not provide the bases for the establishment of a systematic water surveillance network.

1. Intrabasin Inconsistencies

Despite the simple relation between water basin and water agency, surveillance failures were found in data due to breaks in the record, missing information, and changes in laboratory analytical methods. For example, the Bridgeport Hydraulic Company samples the Housatonic River at Shelton, Connecticut, for 13 quality parameters, even though it does not withdraw water directly from the stream for distribution. As Table 6, page 26, shows, six of the parameters were collected weekly for 1960 and 1961, while all 13 were collected monthly thereafter. For both periods, collection of specific parameters was erratic, causing serious gaps in the record. In some years entire months were omitted for all parameters.

Table 6. Number of Observations per Year for Each of 17 Variables Sampled at the Well Field of the Bridgeport Hydraulic Water Company Located on the Flood Plain of the Housatonic River at Shelton, Conn., 1960-70[a] -- Stations 6029 - 6040

	Number of Observations										
Variables	1960	1961	1962	1963	1964	1965	1966	1967[b]	1968[b]	1969	1970
Color	15	19	71	51	58	39	6	1	0	36	34
Turbidity	9	12	26	21	42	25	5	1	0	24	12
Chloride	9	9	21	21	35	25	4	1	0	24	34
Alb. NH3	9	9	21	21	35	25	4	1	0	24	0
Free NH3	9	9	21	21	35	25	4	1	0	24	0
NO2-N	9	9	21	21	35	25	4	1	0	24	0
NO3-N	9	9	21	21	35	25	4	1	0	24	0
Total Hardness	9	9	26	21	35	25	4	1	0	24	34
Alkalinity	9	9	21	21	35	25	4	1	0	24	34
pH	14	19	71	61	58	47	6	1	0	36	34
Total Solids	9	9	21	21	35	25	4	1	0	23	0
Total Fe	14	12	71	41	35	25	4	1	0	23	0
Pumpage	15	19	71	61	47	36	3	0	0	1	0
Coliforms	15	19	71	61	57	39	6	1	0	36	31
ABS	0	9	19	21	31	26	1	0	0	17	2
CO2	14	17	42	28	42	29	3	1	0	22	31
Temperature	14	17	59	58	39	35	5	1	0	28	34

[a] Area of well field is approx. 10 acres; 13 wells are pumped irregularly to supplement other Company sources when needed, mostly in the summer. During pumping, samples are taken monthly for all variables listed, and twice monthly for other variables, more or less regularly.

[b] Composite well samples treated with chlorine and Calgon prior to analysis for 48 observations in 1967 and 1968 are not included; these data were not analyzed.

The Company pumps water from stratified drift wells adjacent to the Housatonic River at Shelton, Connecticut, and a corresponding set of quality data is recorded. These samples are taken, however, only when the wells are pumped -- usually three or four months a year. The result is a widely fluctuating record as Table 6 shows. Parameter and temporal discontinuities make it difficult to compare relations between stream and groundwater. Five miles upstream from Shelton at Stevenson, the USGS initiated monthly water quality surveys for 20 parameters in the 1968-1969 water year. However, only six parameters are common to both stations.

Changes in laboratory analytical methods can be just as serious as a break in the record or the dropping of a quality parameter because they interrupt temporal continuity. Thus, up to March 22, 1966 coliforms were determined by the Bridgeport Hydraulic Company using the fermentation tube method. After that date the millipore filter method was used. The question arises: can these data be treated as a continuous set? Despite the need to update analytical techniques, the importance of maintaining the chronologic integrity of data suggests that the two methods be run jointly until reliable transformation coefficients have been derived.

2. Operations of Data-Collecting Agencies

a. Water Supply Agencies

As was pointed out in the section on New Jersey, producers of potable water have a vested interest in raw water quality because of the impact on treatment costs. Consequently, they monitor the raw water quality on a more or less regular basis and are therefore valuable sources of information. State and local authorities are interested primarily in seeing that the quality of the finished product satisfies health standards.

In Fairfield County there are public and private water companies franchised to produce and/or distribute potable water from surface and underground sources (Connecticut State Department of Health, n.d.). Our project did not have the resources to collect and process all these data. We assembled information from the largest suppliers -- Bridgeport Hydraulic Company (population served 385,000, safe yield 74 mgd) and Greenwich Water Company (population served 60,000, safe yield 14 mgd) -- both of which keep excellent records. Other large producers, from whom data were not collected, are the Danbury Water Department, 6.2 mgd, New Canaan Water Company, 1.1 mgd, Norwalk Water Department, 1st and 2nd Taxing Districts, 10 mgd and 5.6 mgd respectively, and the Stamford Water Company, 14.7 mgd.

The Bridgeport Hydraulic Company maintains an extensive surveillance network on its surface and underground sources. In addition to sampling raw water from its wells and reservoirs, the Company also monitors the Housatonic River at Shelton and the watersheds draining into storage reservoirs. The sampling net is shown by Figure 4. The data taken from company files cover the 1960-1970 decade and are confined to sampling locations on the Saugatuck watershed and reservoir, and the Housatonic River and well field.

Parameters, time periods and locations collected from the Bridgeport Hydraulic Company are given in Table 7, page 32. This project collected 16,396 information bits for processing.*

Data also were assembled from the files of the Greenwich Water Company. The Company draws part of its water from the Mianus River and keeps a weekly record of 12 parameters, at the intake to the filter plant. The project collected this information over a ten-year period -- 1960-1970 -- or a total of 6,216 bits of information, as indicated in Table 7. In addition, discharge was synthesized by adding filter plant withdrawals to flows over the weir below the filter plant. Figure 5 depicts the hydrography of the Greenwich Water Company's source area.

b. Government Regulatory and Scientific Agencies

As part of its inventory of the water resources of Connecticut, the USGS in cooperation with the Connecticut Water Resources Commission has sampled water quality of streams, bedrock, till stratified drift wells, and impounded water bodies in the area. Samples of surface and groundwater were collected at 100 sites that reflected natural conditions. Water was also collected from 17 impoundments. Twenty-one parameters were examined. The samples were taken at various times during the past two decades, most of them being collected during 1960-1970 (Ryder, et al., part 4, 1970; Thomas, 1970; Conn. Water Resources Commission, 1969; and 1970).

For the two stream-sampling stations in this area -- the Saugatuck River near Redding and the Housatonic River at Stevenson -- the early record is missing or spotty. The Stevenson station was sampled only four times during the decade 1950-1960 for 17 parameters (Pauszek, n.d.). No further data were reported until 1967 when monthly samples were taken during the period June through September inclusive. Following that, monthly samples were taken for 22 parameters** for the water years 1968-1969, 1969-1970, 1970-1971, October to September inclusive. The Redding station on the Saugatuck River also was sampled for the same parameter set for the same time period (USGS, 1966, 1967, 1968, 1969, 1970, 1971). Unfortunately, observations at these stations were not integrated with the samples collected by the Bridgeport Hydraulic Company at Shelton and the Saugatuck Reservoir respectively.

*The other sampling sites are: Saugatuck River at Westport, Norwalk River at Wilton, Pootatuck River at Newton, well field of Saugatuck River at Westport and Coleytown, well field of Means Brook at Huntington, Means Brook Reservoir and Watershed, Trap Falls Reservoir and watershed, Far Mills Reservoir and watershed, Easton Reservoir and watershed, Hemlock Reservoir and watershed.

**Chlorides, hardness, conductivity, acidity, turbidity, temperature, dissolved oxygen, per cent saturation, coliforms, discharge, calcium, magnesium, bicarbonate, carbonate, sulphate, phosphate, non-carbonate hardness, fecal coliforms, mercury, and, for the 1970-1971 water year, air temperature, time, streptococci.

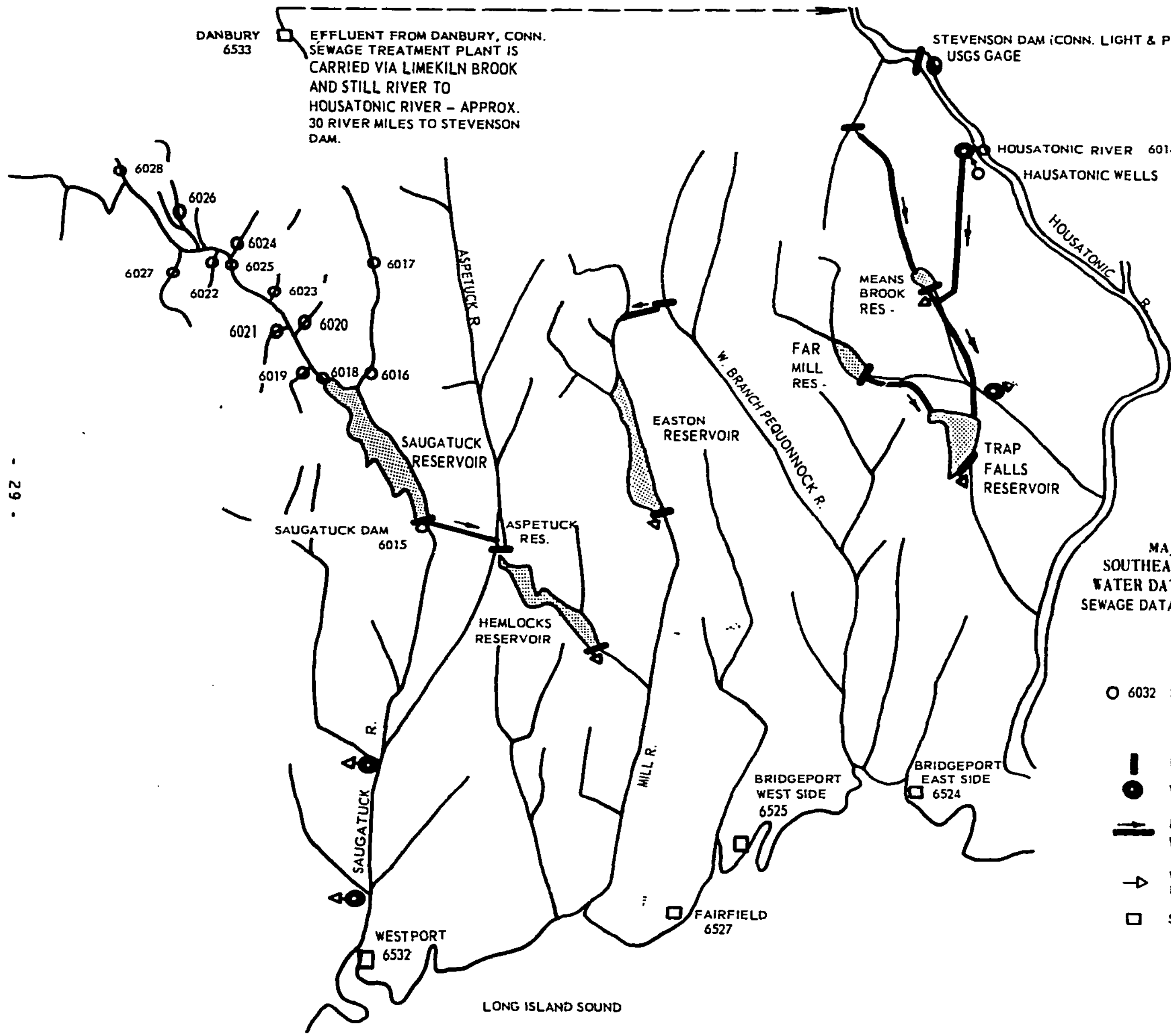


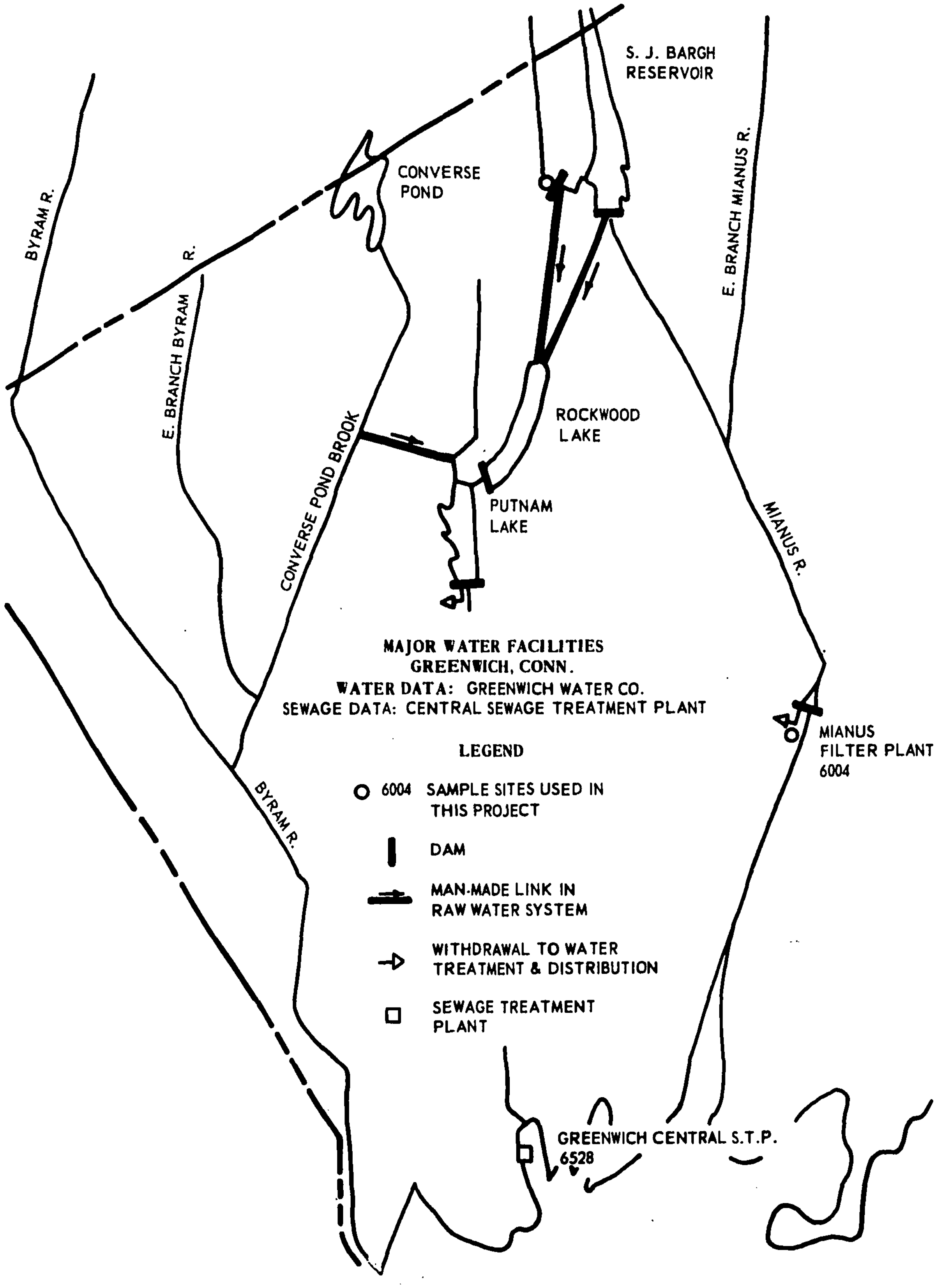
FIGURE 4.

MAJOR WATER FACILITIES
SOUTHEASTERN FAIRFIELD CO., CONN.
WATER DATA: BRIDGEPORT HYDRAULIC CO.
SEWAGE DATA: MUNICIPAL TREATMENT PLANTS.

LEGEND

- O 6032 SAMPLE SITES USED IN THIS PROJECT, WITH PROJECT'S INDEX NUMBER.
- DAM
- WELL FIELD
- MAN-MADE LINK IN RAW WATER SYSTEM
- WITHDRAWAL TO TREATMENT PLANT AND DISTRIBUTION
- SEWAGE TREATMENT PLANT

FIGURE 5.


S. J. BARGH
RESERVOIR
CONVERSE
POND
BYRAM R.
E. BRANCH BYRAM R.
E. BRANCH MIANUS R.
ROCKWOOD
LAKE
CONVERSE POND BROOK
PUTNAM
LAKE
MIANUS R.
MAJOR WATER FACILITIES
GREENWICH, CONN.
WATER DATA: GREENWICH WATER CO.
SEWAGE DATA: CENTRAL SEWAGE TREATMENT PLANT
MIANUS
FILTER PLANT
6004
LEGEND
6004 SAMPLE SITES USED IN THIS PROJECT
DAM
MAN-MADE LINK IN RAW WATER SYSTEM
WITHDRAWAL TO WATER TREATMENT & DISTRIBUTION
SEWAGE TREATMENT PLANT
BYRAM R.
GREENWICH CENTRAL S.T.P.
6528

45

While the overall quality sample data show a good areal distribution, they were not collected at regular time intervals and do not constitute a monitoring data set. In all, a total of 232 samples were assembled and analyzed as the basis for a water quality evaluation.

The USGS also maintains continuous stream flow gaging stations at 23 locations for periods ranging from 18 months to 35 years. Records of the flow at the gaging station on the Housatonic River at Stevenson were added to the quality data obtained from the Bridgeport Hydraulic Company's stream sampling site at Shelton, five miles downstream.

c. Sewerage Agencies

No sewerage systems discharge into any of Connecticut's public water supplies (Connecticut State Department of Health, n.d.). Consequently, the direct relation between water supply and sanitary waste water systems is not present there, as in New Jersey, except for the disposal of domestic and industrial waste to the ground, where aquifer water quality may be adversely affected. In urban areas, waste water is discharged through sewer systems directly into estuaries or into Long Island Sound. Here the effluents contribute to the deterioration of the recreational uses of these waters. However, storm water runoff, overland flow, and industrial effluent do discharge into streams.

The State Department of Public Health, Water Resources Commission, and the Interstate Sanitation Commission require that plant operators submit monthly operator reports on influent and effluent flow, suspended solids, and biochemical oxygen demand (BOD). In addition, periodic samples of sewage plant and industrial effluent are taken by the Interstate Sanitation Commission.

Operator reports were examined and data assembled on 14 sewage treatment plants*. These reports were of uneven quality and covered varying periods of time during 1960-1970. Approximately 4,104 elements of information were collected, as shown by Table 7.

3. Evaluation

Like New Jersey, Connecticut has a widely distributed pattern of stations to monitor water quality and flow and has accumulated a substantial amount of data on many parameters. However, these data cannot be regarded as a surveillance system because of the absence of a design that links the stations in a network. There is, for example, no regularity in the frequency of the observations. Storm water discharge and industrial effluent samples are not taken. In only one area was an attempt made to link the samples systematically and relate the differences to land use. This occurs along a reach of the Norwalk River near Georgetown (Ryder, et al., Part 4, 1970).

*Darien, Fairfield, Greenwich Central, Norwalk, Stamford, Westport, Stratford, Bridgeport Eastside, Bridgeport Westside, Danbury, New Canaan, Ridgefield, Shelton, Bethel.

Table 7. Water Quality Data Bank Summary, Fairfield County, Connecticut

Parameters	BRIDGEPORT HYDRAULIC COMPANY Housatonic R. (weekly 1960-1)	BRIDGEPORT HYDRAULIC COMPANY Housatonic R. (monthly 1962-70)	BRIDGEPORT HYDRAULIC COMPANY Shelton, Well field (weekly, 1961-70 when pumped)	Saugatuck Reservoir (monthly 1960-70)	Saugatuck Watershed	U.S. GEOLOGICAL SURVEY Stevenson (monthly 1962-70)	U.S. GEOLOGICAL SURVEY Stevenson (monthly 1968-71)	U.S. GEOLOGICAL SURVEY Saugatuck R. (monthly 1968-71)	GREENWICH WATER CO. Mianus R. (weekly 1960-70)	SEWERAGE PLANTS
Color		X	X	X	X				X	
Turbidity		X	X	X			X	X	X	
Chloride		X	X	X			X	X		
Alb. NH_3		X	X	X						
Free NH_3		X	X	X						
NO_2		X	X	X						
NO_3		X	X	X						
CO_2			X							
Hardness	X	X	X	X			X	X	X	
Alkalinity	X	X	X	X					X	
ABS			X							
pH		X	X	X			X	X	X	
Total solids		X	X	X						
Temperature			X				X	X	X	
Fe	X	X	X	X					X	
Coliforms	X	X	X	X	X		X	X	X	
Discharge			X			X	X	X	X	
Mn									X	
Bacteria									X	
Conductivity							X	X		
DO							X	X		
Per cent sat.							X	X		
Sewerage flow										X
Suspended solids										X
BOD										X
Information Bits	312	1,088	9,848	1,716	3,432	768	360	360	6,716	4,104
TOTAL									28,704	

47

The private water companies have kept good records of the quality of their raw waters. These records, however, are not mentioned in the official publications as water resources data. Synchronizing the two data sets would expand the whole record geographically, temporally and parametrically.

C. New York

The New York State part of the hydrologic data base may be divided conveniently into the following modules: Westchester County, Nassau County, Rockland County, and their respective offshore estuarial waters. Information on water quality and effluent receipts by the estuary are described in a separate section. The data base on Rockland County has been included in the New Jersey section because the drainage basin of the Hackensack River cuts across the New Jersey-New York state line. The Hackensack Water Company (including its subsidiary operating in Rockland County, the Spring Valley Water Company), is a large private water producer and maintains a water quality-sampling program in both states.* Consequently, this section is restricted to data acquired for the interior upland parts of Westchester and Nassau Counties.

1. Westchester County

The hydrography of Westchester County has been severely disturbed by the works of man and, as a result, forms three distinct patterns:

(a.) The watershed of the Croton River, whose natural drainage outlet is the Hudson River. The Croton basin extends into Putnam County to the north and to the east into Connecticut, and provides the runoff for the Croton Division of the water supply system of New York City.

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*The state of New York lists five sampling stations on the Hackensack River and its tributaries in Rockland County for which water quality data are available. Of these, four are maintained by the Hackensack Water Company and data were collected directly from Company records; one station was deactivated after ten months of operation in 1964; another station maintained by the New York State Department of Health reported data on 46 parameters based on one to 28 samples that varied with the parameter during the water years 1965 through 1967. The set of water quality data assembled from stations throughout New York form a pool of information that purports to be a surveillance network to meet the needs of the State (State of New York, Department of Environmental Conservation, n.d.). Our examination of the details of these data on a print-out obtained from a tape provided by the State Department of Environmental Conservation reveals large blocks of blank information and data irregularities. No active sampling stations were reported for the other drainage basins falling in the study area.

(b.) Southwesterly-flowing streams that discharge into the Hudson River, such as the Saw Mill River, Pocantico River, Hollow Brook and Indian Brook.

(c.) Southerly-flowing streams such as the Hutchinson, Bronx and Sheldrake Rivers that drain into Long Island Sound, and the numerous short streams that flow across the panhandle of southwestern Fairfield County, Connecticut, also discharging into Long Island Sound. Data on the Connecticut streams have been described in that section.

a. Croton Watershed

Imposed on the 373 square miles of natural drainage of the Croton watershed are the water works of the Croton Division of the New York City Water Supply System. The Croton Division furnishes about 25 percent of the City's supply -- 325 million gallons per day, safe yield. The Croton System includes 12 reservoirs and five controlled lakes which impound about 97 billion gallons. In order to maintain the sanitary quality of its water supply, New York City monitors the Croton Watershed at several stations, operates and inspects sewage treatment facilities, regulates the use of herbicides and pesticides, and even directly chlorinates five streams (Bureau of Water Supply, Department of Water Resources, 1969).

At first glance, the mass of uata available appears overwhelming. Closer examination, however, reveals considerable missing observations and breaks in the record. A subset of the complete record was selected for inclusion in our data bank. Table 8 describes the eight stations, the parameters, and lengths of record collected; Figure 6 diagrams the hydrography and locates the stations. Records also are kept for an additional 19 stations, in addition to records of the irregular periodic sampling in various parts of the watershed that go back to the opening of the system. About 16,400 bits of information were collected. The utility of these data for water systems analysis is limited by station-to-station variations in parameters, sampling frequencies and breaks in the record.

b. Streams Discharging into the Hudson River

Several short streams in Westchester County that discharge into the Hudson River are used as sources of water for communities whose supplies may be supplemented by withdrawals from the New York City system. Raw water from local sources is sampled prior to treatment and the record forms the data module for this part of the region. From north to south, the streams and the community which each serves are: Peekskill Hollow Brook (Peekskill), Indian Brook (Ossining), Pocantico River and Reservoir (New Rochelle Water Company), Tarrytown Reservoir (Tarrytown Water Company), Irvington Reservoir (Irvington), and the Saw Mill River and Grassy Sprain Reservoir (Yonkers).

Though in close proximity to one another, the communities and/or water producers are managerially independent and their watersheds are hydrologically separate. This independence is reflected in their water records,

FIGURE 6.

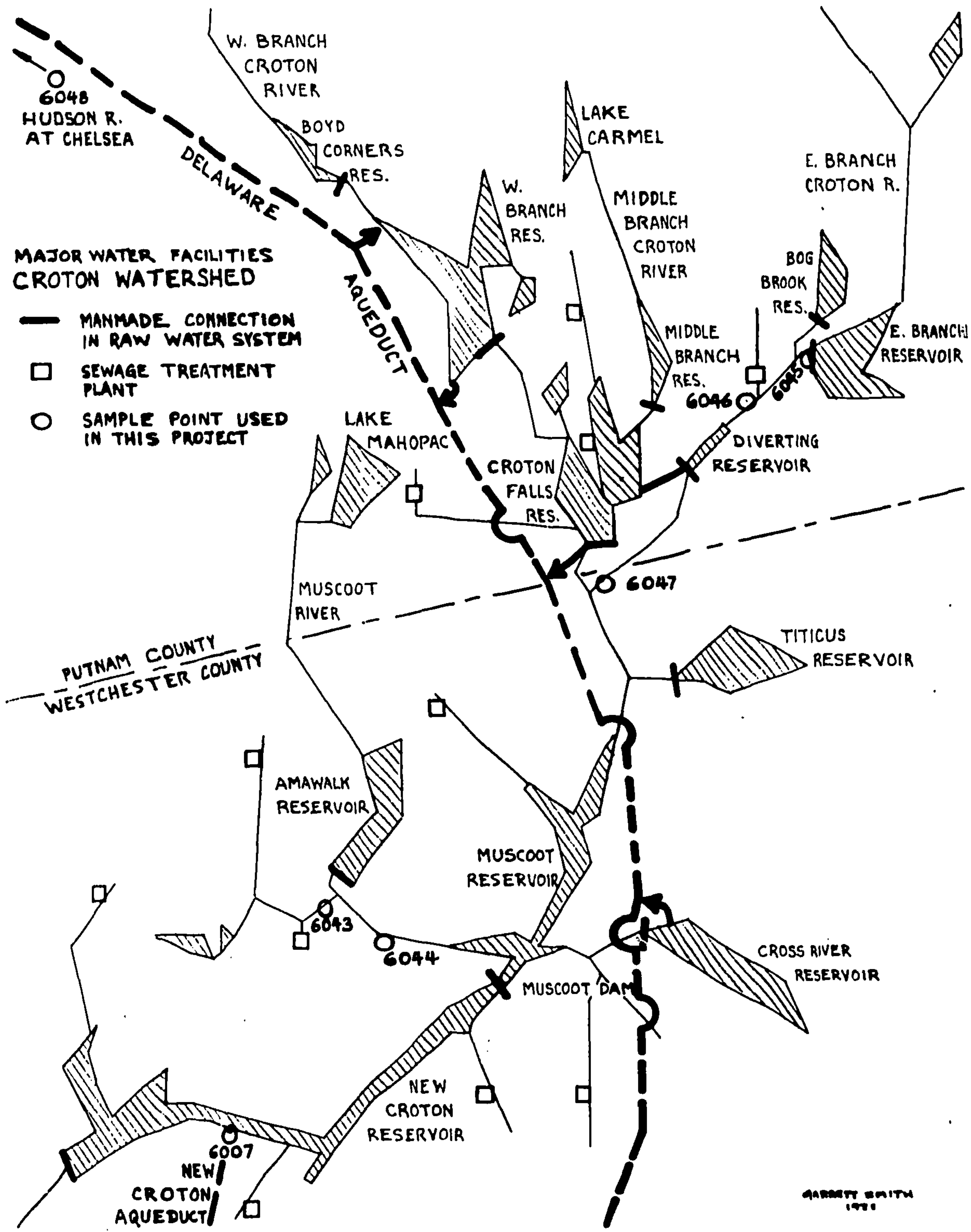

MAJOR WATER FACILITIES
CROTON WATERSHED
MANMADE CONNECTION IN RAW WATER SYSTEM
SEWAGE TREATMENT PLANT
SAMPLE POINT USED IN THIS PROJECT
6048
HUDSON R. AT CHELSEA
DELAWARE
AQUEDUCT
W. BRANCH CROTON RIVER
BOYD CORNERS RES.
W. BRANCH RES.
LAKE CARMEL
MIDDLE BRANCH CROTON RIVER
E. BRANCH CROTON R.
BOG BROOK RES.
E. BRANCH RESERVOIR
MIDDLE BRANCH RES.
6046
6045
DIVERTING RESERVOIR
LAKE MAHOPAC
CROTON FALLS RES.
6047
MUSCOOT RIVER
PUTNAM COUNTY
WESTCHESTER COUNTY
TITICUS RESERVOIR
AMAWALK RESERVOIR
MUSCOOT RESERVOIR
6043
6044
CROSS RIVER RESERVOIR
MUSCOOT DAM
NEW CROTON RESERVOIR
6007
NEW CROTON AQUEDUCT

Table 8. Water Quality Data Collected
Croton Division, New York City
Water Supply System

Station	Length of Record	Frequency	Temp	turb	color	cond	DO	% sat	CO_2	chl	alk	pH	bact	coli	solids	NO_2	NO_3	amor. mat.	hard	PO4	Fe	Mn
Hallock's Mill Brook #1	1960-1968	weekly		X	X	X	√		√	√			X	X								
Hallock's Mill Brook #2	1960-1968	weekly	X	X	X	√	√		√				X	X						√		
E. Branch Croton R., Falls	1966-1968	bi-monthly		X		X					X	X	X	X	X	X	X		X			
E. Branch Croton R., Brew	1966-1968	bi-monthly		X	X	X				X	X	X	X	X	√	√	√		X			
Sodom Reservoir	1966-1968	weekly, bi-weekly	√	X	X	√					√	X	X	√	√	√	√		√		√	√
New Croton Dam, Surface	1961-1968	weekly, bi-weekly, monthly	X	X	X	√	X		X	√			X	X								
New Croton Res., Bridge B	1960-1963	weekly	X	X	X	X	√		√			X	X	X	√		√		√			
Croton Res. #7	1960-1968	weekly	X	X	X	X				X		X	X	X				X				

X = data collected regularly, √ = data collected irregularly which are characterized by parameter and observation frequency differences. In addition, the data subsets exhibit frequent breaks in the record and periods for which constant parameter values are reported. Collectively, they form one of the poorest and least useful data sets in our bank. Table 9 describes this data set which contains about 8,900 bits of information.

c. Streams Discharging into Long Island Sound

The hydrography of these streams fits the pattern described in the section on the drainage basins of southwestern Connecticut; that is, they are small, distinct drainage basins whose streams become tidal estuaries in their lower reaches before discharging into Long Island Sound. These streams are the Hutchinson, Bronx, Sheldrake and Mamaroneck Rivers. Two streams mentioned in the Connecticut section -- the Mianus and the Byram -- have their headwaters in Westchester County. Water quality records for all of the above streams were examined for possible use in this study. The results were disappointing and only data from Sheldrake Lake were collected. The Bronx River is part of the Croton Division of the New York City Water Supply System and is subsumed within it. The data available for Byram Lake were poor, and were not used.

d. Evaluation

The data set for Westchester County proved to be disappointing. With the county's largest interior stream, the Croton, dominated by New York City, our expectations were that a comprehensive model data bank would be available for analysis. Instead, our search revealed uneven record keeping, missing data and record breaks. Our examination of the records of the smaller water systems was also unrewarding. The opportunity to document the long-term effects of urbanization on water quality has been lost.

2. Nassau County, Long Island

The source of potable water in Long Island is groundwater drawn from four aquifers. With increasing urbanization, particularly of Nassau County, the response of water table levels and aquifer quality to diminished recharge, waste disposal and pumpage has been studied intensively for the past half century and has been the subject of numerous studies (Cohen, et al., 1968).

The wells were tested periodically for conformance with health laws and a large body of information was accumulated. Recently, the data were assembled into a rationally organized bank, ordered into a uniform format and entered on punch cards. The 20,000 cards were made available to us for duplication by the Bureau of Water Resources, Department of Health, Nassau County, N.Y.

Information on each of the 390 wells is described by two sets of cards: (a) a master card containing data on well location, owner, aquifer, depth, etc., and (b) parameter cards on which water quality values for 30 variables are entered. Observation frequencies are irregular for wells and parameters. Nevertheless, each of the wells was observed at least once during the length of record, 1949-1970. Data on the duplicated cards were transferred to

Table 9. Water Quality Data Collected - Westchester County Streams Draining into the Hudson River

Water Source	Length of Record	Frequency	Parameters												
			temp	pH	bact	turb	alk	coli	color	CO_2	odor	hard	DO	NO_3	cl
Peekskill Hollow Brock pump house	3/1/62-12/31/64	weekly	X	X	X	✓	✓								
reservoir	4/7/67-12/28/70	weekly	✓	✓	✓	✓	✓	✓							
Indian Brook	1960-1969	weekly		X			X	X		✓					
Pocantico Reservoir	1960-1970	weekly	X	X	X	X	X		X		✓	X			
Tarrytown Lake	1961-1970	monthly	X	X	✓			✓			✓				
Saw Mill River	1966-1970	monthly		✓		✓	✓	✓				✓	✓	✓	✓

X = data collected regularly, ✓ = data collected irregularly tape, labeled, and rearranged in files by aquifers and parameters preparatory to computer processing.* The size of this module is approximately 300,000 bits of information. Figure 7 shows the well locations. General well properties are described by 15 variables, and water quality is evaluated by 30 parameters**. Complete data are rarely available for all parameters (Inter-Agency Committee for Water Resources Data Processing, 1970). Table 10 gives the number of wells observed and the total observations for each year.

3. Queens County, New York City, Long Island

In Queens County, immediately to the west of Nassau County, potable water is produced by both the Jamaica Water Company and the Woodhaven Water Company from wells within the County. Water quality samples are taken from these wells by the Department of Health of the City of New York. These data were collected for the wells of the Jamaica Water Company for the period 1960-1968. The number of wells on which observations were taken for 15 parameters*** varied yearly between 36 and 59. The time and frequency of the observations also varied. A total of 625 observations were made, yielding 10,375 bits of information that were punched on cards.

4. Evaluation

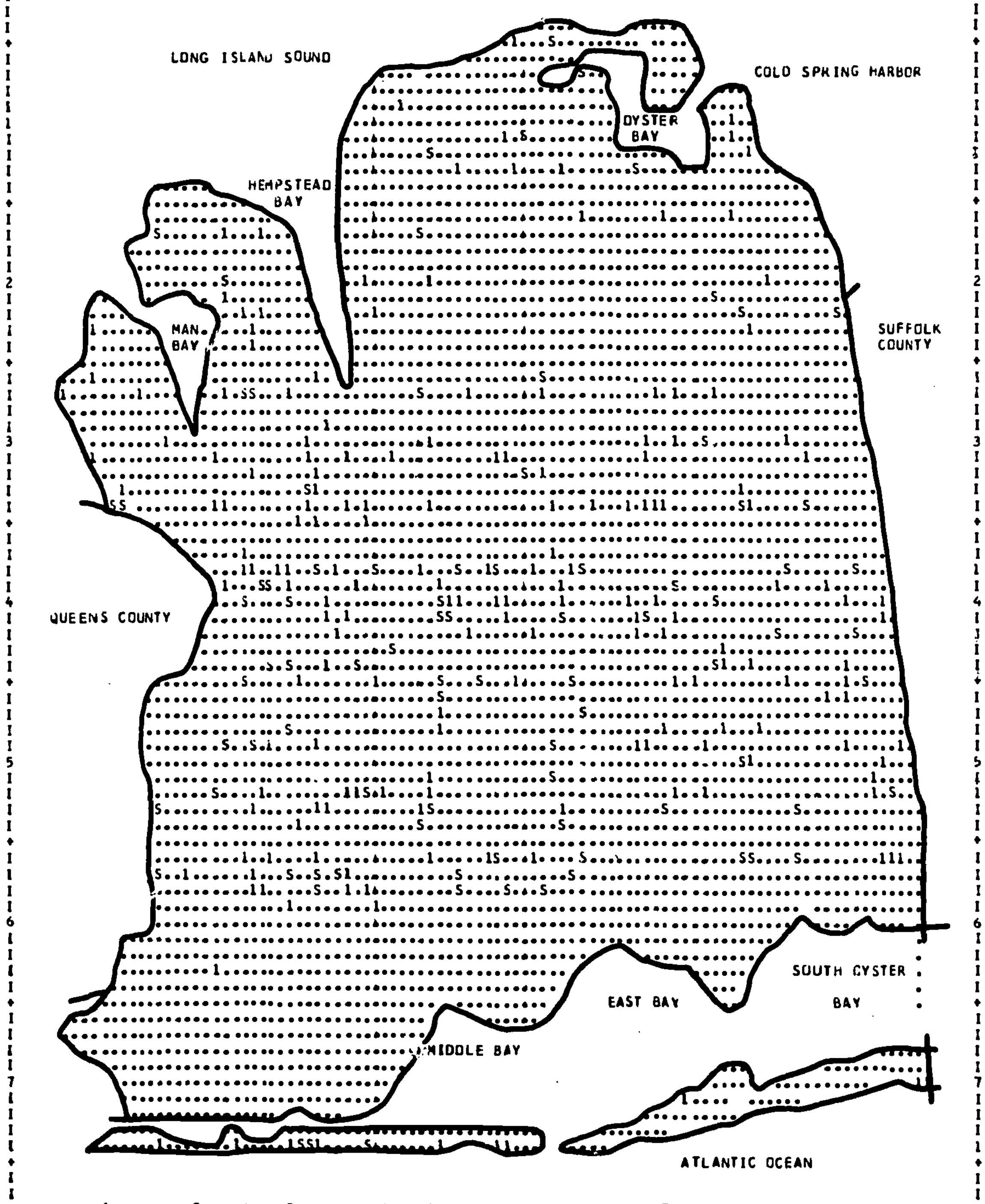
The groundwater data module on Long Island is the best one we have collected. Here, an effort is being made by an interagency committee to assemble a body of information and store it by uniform bookkeeping methods. The attempt is in an early stage and did not, at the time of our field work, include Suffolk County and Queens County. We note also the vigilance that is required in the handling of large masses of data, because of the erroneous format description provided us. The discontinuities and gaps in the record are not due to present failings but derive from the nature of the historic record.

*During the preliminary manipulations of the data, we observed that the format description provided by the Bureau of Water Resources was erroneous. Reformatting corrected the errors.

**Specific conductivity, temperature, chlorine residual, coliforms, plate count, color, turbidity, odor cold, odor hot, pH, total alkalinity, total hardness, calcium hardness, detergents, chemical oxygen demand, dissolved oxygen, oxygen consumed, Fe, Mn, total phosphate, ortho phosphate, fluoride, CO_2, total solids, NH_3, alb.N, NO_2, NO_3, chlorides.

***Temperature, turbidity, color, NH_3, total N, NO_2, NO_3, specific conductivity, total solids, chlorides, hardness, alkalinity, pH, iron, CO_2, oxygen consumed, alkyl benezine sulphonate, manganese, bacteria.

Figure 7



SYMAP

4.0 SECONDS FOR MAP

TIME = 68595.2

C WELLS, NASSAU COUNTY, LONG ISLAND, NEW YORK

C "S", MORE THAN ONE WELL AT THIS LOCATION; "1", LOCATION OF ONE WELL

Table 10. Number of Wells Observed and Total Observations, Nassau County, Long Island, 1949 - 1970

Year	Total Wells Observed	Total Number of Observations
1949	1	1
1950	3	3
1951	0	0
1952	81	92
1953	67	76
1954	124	152
1955	81	94
1956	39	47
1957	137	157
1958	63	66
1959	79	86
1960	171	207
1961	188	216
1962	265	341
1963	264	277
1964	276	299
1965	319	386
1966	328	397
1967	312	424
1968	366	496
1969	353	495
1970	285	324
TOTAL	3802	4636

D. The Estuary

The estuarial waters of the NYMR touch the mainland shore lines of three states and their offshore islands, forming more or less distinct but hydrologically connected estuarial subunits. The larger divisions are, beginning in the north and moving in a clockwise manner: lower Hudson River, the Harlem River, the East River, Long Island Sound, the bays lying between the south shore of Long Island and the offshore barrier islands, the Atlantic Ocean, lower New York Bay, Raritan Bay, Arthur Kill and Kill Van Kull, Newark Bay, and upper New York Bay. In addition to receiving the discharges of the fresh water streams which become tidal in their lower reaches, the waters of the estuary also receive raw and treated sanitary and industrial effluents and the storm runoff from the array of land uses that occupies its immediate drainage area. These waters are frequently referred to collectively as the New York Bight. They are utilized for transportation, waste disposal, fisheries and recreation.

We have attempted to collect the historic record of the changing qualities of the estuarial waters as part of our effort to assemble a comprehensive data bank. During the course of this part of our investigation we again experienced the frustrations of poor record keeping, accessibility obstacles, parameter and temporal discontinuities, and jurisdictional confusions among the responsible agencies.

1. Intraestuarial Inconsistencies

Despite the fact that the estuary is a single hydraulically inter-connected body of water it is chopped up into a variety of political jurisdictions. As a result, responsibility for monitoring its quality is parceled among at least five agencies. In some parts of the estuary, more than one agency performs the task. This situation did not arise by design, rather it evolved. The impact on the estuary of increasing intensity of its use for waste disposal conflicted with the growing demand to utilize its recreational and fishery resources. Agencies were authorized to monitor particular parameters and/or parts of the estuary as awareness of the issues emerged. Each agency received a mandate that reflected the objectives of its empowering body. Thus, operations were restricted geographically, temporally and parametrically, and, occasionally, sampling was duplicated. The result of this history is a plethora of information-gathering agencies, the accumulation of large incongruous data sets, and a geographically distorted sampling pattern.

The areal distribution of stations reflects the history of surveillance in the metropolitan area. More stations are concentrated in the eastern and central portions of the estuary, notably the harbor itself and Raritan Bay, and comparatively little effort has been exerted in the eastern and northern sections of the estuary, as shown by Table 11.

When, to this already confused situation, there are added budgetary fluctuations and crash sampling efforts in response to crises, the investigator finds himself engulfed by a vast avalanche of data in varying states of order and disarray. Taken together, these data do not add up to a congruent body of information on the estuary.

Information on the estuary has been collected by the City of New York (Department of Water Resources and Department of Health), Environmental Protection Agency of the Federal Government (and its predecessor agencies), Interstate Sanitation Commission, New Jersey Dept. of Environmental Protection, and by communities in Nassau, Suffolk, and Westchester Counties, New York, and Fairfield County, Connecticut.

The agencies have generated water quality data at 431 stations on twenty parameters. For the purpose of discussion, these efforts can be divided into four groups based on the manner and frequency in which water quality data have been collected: a) manually, and b) electronically; c) short term surveys, and d) data gathered through a continuous water quality surveillance. They are summarized in Table 12.

Data have been obtained from five different agencies and comprise information from seven different sources.*

Although the data set is large, amounting to approximately 140,000 punch cards estimated to contain some 1-1/2 million bits of information, its value is severely limited because of an almost complete lack of coordination. Some of the more apparent reasons are discussed in the next section under agency operations. An impression of the confused character of the data can be obtained from Table 13.

2. Operations of Data-Collecting Agencies

Several local, state and federal agencies collect data from the metropolitan region. Their efforts are often spurred by minor water quality crises felt by specific user groups. The result has been a specialization characteristic of each of the agencies involved. The Department of Water Resources of New York City has collected water quality data from

---

*Two of the sources were obtained from an agency which did not collect and analyze the data. Thus, one extensive survey was the result of a semi-public effort conducted by E. R. Segessar and M. C. Rand entitled "Raritan River-Raritan Bay Survey Summary Report" (unpublished paper). This work was conducted in an attempt to determine the before-and-after effects of the Middlesex County Sewerage Authority outfall in the western part of Raritan Bay. These surveys were obtained from the Interstate Sanitation Commission (ISC).

Another larger block of data originally collected and analyzed by the Bureau of Water Pollution Control, N.Y.C., Department of Water Resources, was obtained from the Water Quality Office, Environmental Protection Agency (EPA), Edison, N.J. Initially, there was considerable resistance by the City of New York to release this and other data. During the final months of the project this resistance was overcome, but at that time the data bank had already been assembled. Data from two other sources were available but not included in the analysis because of variable selection or insufficient numbers of stations located within the study area.

Table 11. Percent of Stations in Parts of the Estuary

Upper Harbor	7
Kill van Kull & Arthur Kill	15
Raritan Bay	42
Newark Bay	9
Lower Hudson	4
Tappan Zee	8
Hudson River, Newburg	2
West Long Island Sound	1
East River	5
Eastchester Bay	2
Jamaica Bay East	1
Jamaica Bay West	3
Rockaway Beach	1
	100

Table 12. Estuarial Data Sources

	Continuous Surveys	Short-Term Surveys
Manually Collected Data	Interstate Sanitation Commission	Interstate Sanitation Commission
	N.Y.C. Department of Water Resources	Environmental Protection Agency
	N.Y.C. Department of Health	
Electronically Collected Data	Interstate Sanitation Commission	
	Environmental Protection Agency	

Table 13. Estuarial Sampling Agencies and Sampling Methodology

Agency	Sampling Period, Frequency, Location	Parameters
New York City, Dept. of Health	from 1958, hourly samples 6 a.m.-6 p.m., May 10-Sept. 15; 16 sampling points off Brooklyn, Manhattan, Bronx, Queens	Coliform
New York City, Dept. of Water Resources (New York Harbor Survey)	from 1909 (except 1910), weekly samples during June, July, August; 44 sampling points in Hudson R., East R., Harlem R., Long Island Sound, southern bays of Long Island, Jamaica Bay, Atlantic Ocean, Kill Van Kull, Arthur Kill, Lower New York Bay, Upper New York Bay, Raritan Bay	BOD, DO, turbidity, temperature, coliforms
Federal Environmental Protection Agency (EPA)	from 1963, automatic robot instrumentation, samples at 15 min. intervals over a 24 hour period; 5 stations in Kill Van Kull, Arthur Kill, Raritan R., Raritan Bay, Rosebank off Staten Island	wind direction and speed, solar radiation, turbidity, conductivity, O_2 reduction, pH, DO, temperature
New Jersey, Dept. of Environmental Protection	from 1968, 20 samples during summer, shellfish surveys; 60 stations in Raritan Bay	Coliform, tidal stage, wind direction and velocity
Interstate Sanitation Commission (ISC)	from 1957-1970, 22 special surveys made in parts of the estuary; duration of surveys, frequencies, locations, and parameters vary; Raritan Bay 8, Raritan R. 2, Arthur Kill 3, Kill Van Kull 2, Passaic R. 1, East R. 2, Upper Harbor 1, New York Harbor 1, Hudson R. 1, Newark Bay 1	Varies from 3 to 16 for each survey
Local Communities in Westchester, Nassau and Fairfield Counties	miscellaneous surveys of bathing beach waters during the recreation season	Coliforms

the harbor since 1909 with only one interruption. This work represents a consistent record which has been updated once through the addition of a few variables. A report dealing with the updating of this survey could not be obtained.* The maintenance of the annual harbor survey is an excellent example of an effort prompted more by custom and habit than by any need for information concerning water quality and its relationship to public health.** The City of New York through its Bureau of Sanitary Engineering, is also responsible for collecting water quality data from the public beaches lying within the City limits.***

The New York City Department of Water Resources monitors the Hudson River at the emergency intake plant at Chelsea, where its Delaware aqueduct crosses the river -- about nine miles south of Poughkeepsie. The water is tidal and fresh at this point, and is blended with upstate water when supply runs low. The record goes back to January 1, 1967 and consists of daily observations (occasionally more frequent) on 11 parameters. Continuity of all records, however, is disturbed by irregular and regular periods of missing data for particular parameters, sampling omissions while the river was frozen, and a "no observation" pattern on weekends and holidays. Another break in the record occurs because of a change in the sampling point. Initially, samples were taken by means of a pipe that extended above the intake main 500 feet into the river. A break in the line after about two years of operation caused the sampling point to be shifted to a position 30 feet from the shoreline.

Although this data set is one of the best we collected, its shortcomings illustrate the empirical difficulties we faced. Because its failings could be pinpointed, it was a valuable source of design recommendations for the improvement of a surveillance network discussed later. In total, about 1,030 observations were collected on eight parameters, yielding a total of approximately 8,650 bits of information. Table 14 summarizes the properties of the data bank.

*We attempted on a number of occasions to gain access to this report, but to no avail.

**This agency is by no means the only one that maintains long-established sampling programs. Coliform counts are collected by all agencies not because of a relationship between coliform, effluent and public health, but because a long record has been established which would be destroyed should other more significant water quality parameters be selected. The measure of water quality has been institutionalized and thus it has become very difficult to change. This discussion is particularly relevant in view of weak or nonexistent relationships between effluent sources, coliform and public health.

***Several of the counties, cities and townships have initiated programs of coliform and fecal coliform measures as the single most important indicator of human effluents. The value of these measures is limited because of the nonstandardized form in which they are being taken, and, more importantly, because of questions pertaining to the use of coliform count as an indicator variable of human effluents.

Table 14. Data Summary, Hudson River, Chelsea, N.Y. (Jan. 1, 1967 - June 25, 1971, except on weekends and holidays)

Parameter	1967	1968	1969	1970	1971
Temperature	X	X	X	X	X
Turbidity	X	X	ND 2/28-4/30	X	X
Specific Conductivity	X	X	X	X	X
Chlorides	X	X	X	X	X
Hardness	ND 1/1-4/11	X	X	X	X
Alkalinity	X	X	X	X	X
pH	X	X	X	X	X
Dissolved Oxygen	ND	ND 1/1-4/21	X	X	X
Percent Saturation	ND	ND 1/1-4/21	X	X	X
Bacteria*	X	X	X	X	X
Coliforms*	X	X	X	X	X

ND = no data

* = 3 days per week

Four stations in the lower Hudson have been sampled for several parameters and for varying periods of time, but they do not constitute a useful data set (USGS, 1969).

Survey efforts of the federal government's Environmental Protection Agency (EPA) have suffered from periodic financial constraints. Unlike the local governments, this agency has the mandate to study the water quality for the whole New York region. In addition, attempts have been made to coordinate the research and surveillance work -- an attempt which has also been curtailed due to budgetary constraints.* An additional constraining factor which may be more severe than the size of its budget is the manner in which this agency is financed. EPA, like all other federal and state agencies, submits its budgets annually. Because its efforts in long-term planning have been severely hampered by fiscal fluctuations, its estuarial research has been limited by uncertainty about future allocations. As a specific example, EPA has had to scale down a five-year water surveillance project in the Raritan Bay to one of two years' duration.

Budgetary pressure in the case of the Interstate Sanitation Commission (ISC) arises from different causes. Despite its limited resources, the ISC has not been subjected to fiscal fluctuations, with the result that its work has progressed continuously. A relatively small proportion of this agency's research effort is spent on continuous surveillance of three stations located in the Raritan Bay, Raritan River and Arthur Kill. In addition, a sporadic effort has been made in sampling the harbor on a weekly basis in approximately the same areas as N.Y.C.'s Harbor Study. The real problem in the case of ISC is that this agency relies on the Army Corps of Engineers for transportation. This cooperative effort has been waning in recent years with the result that ISC's continuous harbor survey has become increasingly disrupted.**

Apart from its growing emphasis on industrial and municipal effluents, ISC has spent a large proportion of its research efforts on relatively short-term intensive surveys in smaller parts of the estuary, with a tendency to increase the variable set in these surveys.*** For purely descriptive purposes, this effort seems entirely justified. If, however, the objective is to investigate the very complex spatial and temporal relationships presumed to exist within the estuary, this approach seems to be less than adequate.

Both ISC and EPA have begun to use automated (electronic) monitoring of the estuary. Two major problems appear to limit the utility of these machines at present. First, the variables included are limited to those which can

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*The EPA is the only agency which has actively pursued a cooperative effort by the agencies currently conducting research in the estuary. Although some progress has been made, particularly between EPA, ISC and the various county conservation departments, there is room for much more cooperation.

**Some additional areas of cooperation exist between the two agencies. Army Corps of Engineers (ACE) does not operate any water quality labs. Some of this work is performed by ISC.

***This agency started to collect data on heavy metals during 1970.

be measured electronically. This has resulted in a parameter set which in some instances is largely unrelated to the parameters collected elsewhere. The reason for their inclusion in the ISC and EPA automated system and their relevance to water quality is not well understood. In some instances, the parameters seem to be governed more by what was technically feasible at the time the monitor was designed and less by the parameters which are believed to play a role in affecting the water quality within the estuary. The second important limitation of the automated monitors is the maintenance requirement. Large gaps existed in the EPA records for 1969 for the four monitors managed in the estuary by this agency. ISC has recently engaged one engineer whose sole duty is to calibrate and maintain the agency's automated instruments. Both agencies have committed themselves to an increased use of automated monitors.

A large mass of data has been collected by the state agencies responsible for private and commercial shellfishing. Their data were not used because of the limited variable set and because most of the shellfishing areas located within the study area have been closed due to excessive pollution. As a result, these areas are not sampled as frequently as those which are still considered clean and which allow commercial harvesting of the shellfish.

Under a tristate compact between Connecticut, New Jersey, and New York, the ISC was given the responsibility to provide for the abatement of existing water pollution and the control of future water pollution in the tidal waters of the NYMR. In addition to monitoring the quality of the estuary, as described above, the ISC receives reports from sewage plant operators and also samples waste water effluents from industrial and municipal plants. The estuary receives the discharge of 50 primary and 37 secondary treatment plants. Data on inflow, outflow, suspended solids, and BOD reduction were collected. In 1970, these plants discharged 767 mgd of primary-treated sewage and 1,245 mgd of sewage receiving secondary treatment. In addition, 451 mgd of raw sewage were discharged (ISC, 1970 report).

Monthly operator reports also were collected on the municipal sewage plants discharging effluent into the estuaries. The parameters recorded include flow, suspended solids for influent and effluent, BOD for influent and effluent, and sometimes dissolved solids. Taken as a whole, there was wide variation in length of record, continuity of record, parameters and reliability. The records appear to be most useful for the summer chlorination periods. A total of about 8,000 bits of information were collected. The estuarial sewage treatment plant data bank is summarized in Table 15.

Data for 66 variables initially were collected from all five data sources. Some of these were limited in the numbers of observations and others were limited to a very few stations. A third group, of six qualitative variables determined subjectively by direct observation, (discoloration, oil and grease, floating solids, odor, weather, and wind direction) was excluded because of an apparent lack of uniformity in reporting these data.*

*Serious questions were raised as to the validity of these data. Since it was found that on days with inclement weather visual observations were often absent, it was decided not to include these variables in the analysis.

Table 15. Sewage Treatment Plants Discharging into the Estuary* (Primary and Secondary, 1970)

Plant Location	Flow (Mgd)	Est. Population Served
New Jersey		
Bergen County	2.1	5,000
Hudson County	80.9	293,741
Middlesex County	109.2	675,000
Monmouth County	3.2	20,900
Union County	76.0	531,000
Essex County	250.0	2,899,000
New York		
Nassau County	91.9	788,000
Rockland County	14.9	34,000
Westchester County	113.1	747,000
New York City		
Bronx County	150.1	775,000
Kings County (Brooklyn)	414.5	3,635,535
New York County (Manhattan)	259.7	1,509,000
Queens County	286.0	1,756,000
Richmond	26.5	145,000
Connecticut		
Fairfield County	76.8	394,500
TOTAL	1,954.9	14,208,676

*Source, ISC, 1970 report

Variables for which less than 50 observations were made were also excluded from further analysis.* The variables included in the analysis appear in Table 16.

Important information on the discharge of raw sanitary and industrial effluent during wet weather was not available. The location of bypass regulators and associated drainage areas to prevent flows into sewer plants that exceed their capacities apparently is not known by the managers of combined sewerage systems in older parts of the region. Such information is essential to assess the responses of receiving waters. A preliminary attempt to prepare these maps indicated that the effort was well beyond our resources.

The lack of information about qualitative and quantitative aspects of the estuary's physical condition underscores the need for creating a water quality surveillance network which reflects the natural as well as man-induced processes occurring within it.

It was originally intended to include that part of the estuary bordering the core and intermediate ring of the tristate metropolitan region. This plan had to be abandoned due to the lack of a data set consisting of representative variables covering a sufficiently large area. In some cases -- e.g., off Long Island -- a suitable number of stations could be located, but the variables included in the data set were very few. This is particularly true in the case of the south shore of Long Island. In other areas -- as on the Hudson River -- the limiting factor was not the data set, but the few stations which had been sampled. Even within the region as finally defined, great disparity exists in terms of the density of stations and frequency of observations.

The volume of the information combined with its extreme temporal and spatial unevenness necessitated further standardization and reduction. For this reason data preceding 1960 were excluded from further analysis.**

Since one of the research objectives was to investigate the relationship between water quality and water-based recreational activity, it was decided to limit the data set further by including only those data collected between April 1 and October 31. This is the period of greatest recreational use.

*The majority of these data were collected and analyzed by EPA. An agency depends on annually-appropriated funds, and therefore subject to severe limitations in its long-term surveys. The result appears to have been an intensive effort in relatively short-term surveys limited in their geographical coverage and yielding answers to very specific water quality questions. The more desirable objective would have been a greater research effort in the selection of representative parameters followed by a continuous surveillance of the estuary for the purpose of discovering long-term changes.

**Only one exception was made. A good data set was collected from the Raritan for the period extending back to 1957. These data, obtained through the office of the ISC, were the first to be collected, long before the temporal and spatial constraints of the total data set were fully realized.

Table 16. Variables and Number of Observations for Each in New York Metropolitan Estuary Sample

Air temperature	250
Water temperature	376
pH	192
Dissolved Oxygen	302
Biochemical oxygen demand	228
Chlorides	239
Conductivity	109
Turbidity (Jackson Units)	102
Nitrite	86
Nitrate	95
Chemical Oxygen Demand	51
Coliform bacteria (Membrane filter)	152
Fecal Coliform bacteria (Membrane filter)	144
Streptococci bacteria (Membrane filter)	113
Kjeldahl Nitrogen	55
Ammonia Nitrogen	41
Phenol	68
Phosphate	69
Ortho Phosphate	75

Since most recreational activities take place in the surface waters, all observations of water quality in the lower and intermediate parts of the water column were excluded as well. The limitations imposed thus far reduced the data bank by approximately 50 percent.

Ultimately, information was obtained from 876 stations.* Of these, 48 percent (445) had to be discarded because of lack of information. In a number of instances the location of the station could not be determined with sufficient accuracy to warrant its inclusion in the final data set.** In a few instances, station locations were defined although no data could be found.***

In addition to the data described above there is a large body of information collected by Long Island municipalities on the recreational qualities of their offshore waters. The value of this material for our purposes was limited, and, in any event, the effort to assemble it was beyond our resources. A variety of reports and special studies on the quality of all waters of the Atlantic Ocean, the South Shore bays of Long Island, Long Island Sound, and the North Shore bays also have been made. Again, the data were of limited value to us, largely because of their short lengths of record and inconsistencies of the parameters selected (Department of Health, Education and Welfare, 1965,; Environmental Protection Agency, 1971a, 1971b; Manganaro, Martin, and Lincoln, 1966; Federal Water Pollution Control Administration, 1966, 1967, 1968, 1969; Nassau County, 1968).

3. Evaluation

A great deal of time, effort, and money has been invested in monitoring the waters of the New York Bight. Our observations indicate that the returns in the form of scientific knowledge and managerial guidelines have been limited. The water quality data for the estuary are characterized by a plethora of surveys, each of which is designed for a restricted and, often, very specific purpose. The present sampling effort is symptomatic of the patchwork management of the resource, resulting in sampling efforts which sometimes overlap in area and frequency and, at other times, leave large

*Where several agencies have collected data for a specific station, each data set was identified by an independent station number. Of the 431 stations used, 13% were sampled by two or more agencies.

**One agency -- the N.Y.C. Department of Sanitary Engineering -- submitted data from 100 stations. Although several visits were made to the office after the data assembly had been completed, only 43% of the stations could ultimately be located.

***The data retrieval system in all but a few instances left a great deal to be desired. Records were often stored in manila folders or loose binders without any clear identification. This seems strange in view of the fact that some of the data are guarded rather jealously. In one instance our data collection was terminated very abruptly and was not resumed until an exchange of letters had stated our affiliation and study purpose.

areas unsurveyed for extended periods of time. Parameters are often omitted or they differ from agency to agency. Sampling accuracy and data reliability are questionable. In our judgment the estuary presents a great opportunity and need for the design of a geographically valid sampling network.

E. Design Elements of a Metropolitan Area Water Surveillance Network

The previous sections of this chapter have detailed the actual operations of a water quality surveillance network in the NYMR. The network's structure and behavior, as an information-gathering system for urban water management decisions, reflect the interplay of numerous forces and interests -- political and jurisdictional fragmentation, official over-optimism based on an assumed abundance of the water resource, state of hydrologic knowledge, a pattern of crisis-inspired responses, bureaucratic competition, and the inertia of habit. The present arrangements cannot be regarded as a network if by that word we mean coordinated entities responsible for gathering information on events or conditions and for relating all the bits of raw and spent water data to one another so that they bear on local and regional water management and policy decisions.

The following recommendations, based on our field experiences, describe the elements of a metropolitan area water surveillance network and their integration into a goal-oriented information system.* Among the advantages of reducing the current disorder are: transferability of data from one agency to another, feasibility of simulating the responses of water bodies to natural and man-induced hydrologic events, evaluation of alternative abatement methods, reduction of the time period between the recognition of a pollution problem and its solution, prediction of undesirable quality levels, identification of appropriate preventive measures, environmental impact review of short-term and long-term regional land and water policy decisions.

The organization of a hydrologic data base would provide essential inputs into a managerial structure in charge of long-term water policy formulation and short-term regulatory and allocational decisions. The ten elements of such a data base purposely bypass the difficulties associated with actual sample collection and laboratory analysis, not because we wish to minimize these problems, but because we wish to stress the broader design components of a monitoring network.

(1) Parameter identification
(2) Selection of water bodies and effluent dischargers
(3) Location of sample points
(4) Observation frequencies
(5) Selection of sample sites
(6) Choice of sampler and sensing instruments
(7) Analyzing samples and scaling results
(8) Bookkeeping practices
(9) Data storage and retrieval
(10) Systemic properties of data

*The importance of the subject is indicated by a recent symposium (Kerrigan, 1970).

1. Parameter Identification

A first crucial element is the selection of the parameter set appropriate to the existing or anticipated uses of the water body. The total set of possible parameters probably amounts to at least 93 variables (Porterfield, 1970). They are divisible into several categories: hydrological and meteorological -11; physical -14, inorganic chemical -33; organic chemical -9; nutrient -9; microbiological -10; biological -7. The list could undoubtedly be expanded, as knowledge of toxic, trace, and radioactive materials and the use of synthetic compounds grow. It seems neither necessary nor feasible to monitor all the parameters. Some adjustment of parameters to land use, industry and the hydrology of the water body can be made. For example, trace metals could be monitored in the spent water prior to discharge; meteorological variables would be more significant in estuaries and impoundments than in free-flowing streams.

Our screening of large masses of data revealed that substantial economies are possible of the monitoring effort because of high intercorrelations among some variables. The number of variables to be monitored in the water body is also closely tied to the operational efficiency of the regulatory agencies responsible for inspecting industrial and municipal discharges. If potential sources are kept under reliable surveillance, the number of episodic events may be reduced to a level which would obviate constant monitoring of the water body for a large number of parameters.

There is also evidence that some widely sampled variables yield information that is superfluous, misleading or unreliable. Among the suspect variables, institutionalized by virtue of their long histories as water quality indicators, are: color, odor, carbon dioxide, air temperature, and coliform counts -- the latter as a criterion of contact recreational uses.

2. Selection of Water Bodies and Effluent Discharges

As an interconnected water network characterized by hydrologic subunits, the urban water regime should be monitored in a way that reflects its diversity. It is composed of free-flowing streams; impounded streams; impoundments (lakes and reservoirs); tidal fresh water; estuaries; aquifers; and nodes or confluences at which flows mix, water is withdrawn and spent water is discharged. Water bodies that are unique aquatic environments should be monitored separately. In addition, each use zone -- existing or planned -- should be included in the sample. In establishing such use zones, outfall locations of municipal treatment plants and large industries, discharge of bypass wet weather-flows and surface runoff all merit consideration as man-designed junctions.

The urban water regime is a complex aquatic system both in its natural hydrologic behavior and in its response to effluent receipts. The surveillance network should take cognizance of these variations.

3. Location of Sample Points

The places at which samples are withdrawn should reflect the hydrologic diversity so that the contribution of one sector to its adjacent sectors can be evaluated. [illegible] their flows are unidirectional, [illegible] residual time or unit-travel time within a sector may vary. In the lower tidal reaches of the streams and in the estuary, flows are multidirectional. In other words, the sample locations should be arranged to form a pattern that resembles the hydrologic structure, including engineering works. Figure 8 is a schematic diagram of one possible sampling pattern. Within a hydrologic unit, additional subdivisions that merit sampling may be identified to trace flows and observe offshore and near-shore gradients.

4. Observation Frequencies

The interval of time between successive samples should be regular and uninterrupted, except for good cause. Repeatedly, we have observed that time periods between samples have been uneven because of weekends and/or holidays. Such irregularities reduce the utility of the data set. Several types of time series analysis -- e.g., harmonic analysis -- require constant observation intervals. In addition, breaks in the record increase the probability of unrecorded events.

The two ends of the observation frequency continuum are "grab" samples and continuous monitoring. Grab sampling -- widely used for spot inspections by regulatory agencies or as a politically-inspired cosmetic response to crises -- yields instantaneous information about specific parameters. It is extremely hazardous to attempt to relate grab findings to the same or different parameters for the same water body and for other water bodies.

At the other end of the spectrum, continuous monitoring at short time intervals -- usually 15 minutes -- is possible with robot instrumentation. It is doubtful if so frequent a sampling is worth the effort, even if it can be carried out for extended periods. The resulting avalanche of information would be a deterrent to meaningful analysis. Our limited examination of such continuous records indicates that many breaks occur in the record despite impressive statements about the capabilities of robots.

Between the two end points lies a vast range of possible sampling time intervals. The question of deciding on the best frequency is not resolved easily. It depends on the behavior of the parameter, the response time of the water body and the object of surveillance activities. (In one study of a data set on the Raritan River, New Jersey, composed of daily, weekly and monthly observations, we found parameter correlations and trends similar for daily and weekly frequencies.) Hydraulic behavior of water bodies influences response time to given waste loadings and this will affect both sampling frequency and evaluation of findings. Streams, lakes and estuaries differ in their magnitudes of quality responses. Similarly, the variability of load fluctuations in waste effluents is important in determining sample size (Thomann, 1970).

If the purpose of monitoring is to record long-term trends and changes in the state of the water body, the sampling texture can be coarser than if the object is regulatory or the recording of episodic events. Detection of episodic occurrences is more effectively achieved by direct, frequent monitoring of the effluent rather than the receiving water. This method has the added advantage of identifying the source.

SAMPLING PATTERN AND HYDROLOGIC STRUCTURE

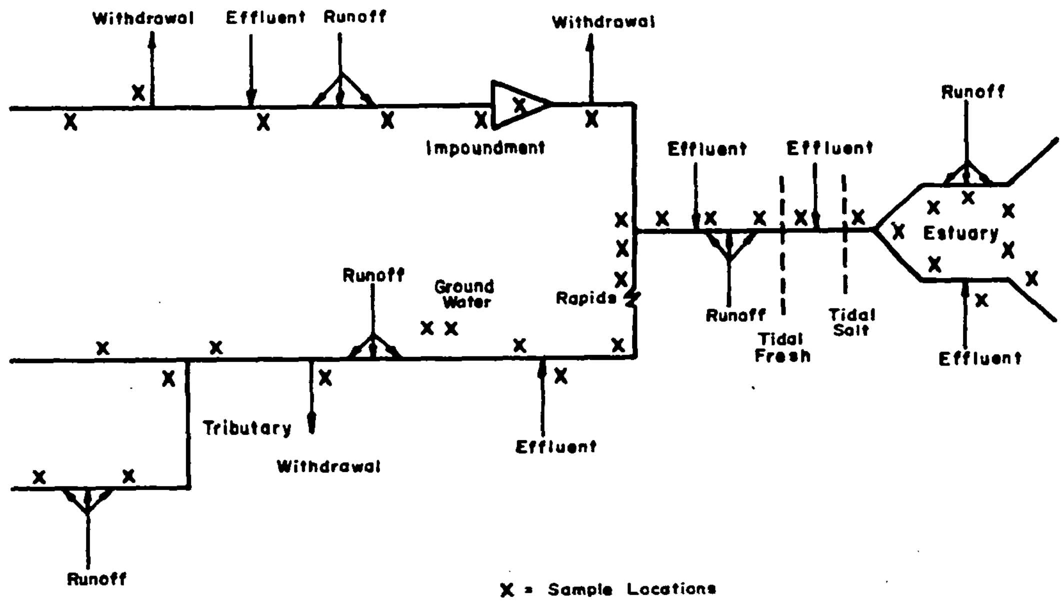

Figure 8

Our experience indicates that daily or weekly observations are adequate for most purposes. The actual time of sampling should also be recorded and every effort made to keep the interval of time constant to reduce sampling bias.

Observation frequency, geographical location and site selection jointly determine the field sample design, which must be sensitive to the spatial and temporal variabilities of water quality and waste loadings. In organizing sampling strategies, some prior knowledge is assumed. If this is not available, preliminary investigations will be needed.

5. Selection of Sample Sites

Once the water body and the sample location have been selected, the precise point at which the sample is withdrawn must be determined. There are at least two alternatives that reflect lateral and vertical stratification in water quality: (a) horizontal distance from shore banks, or obstacles, and (b) depth. Both are important. Additional study is needed to evaluate midstream and bank sampling. It is possible for slugs of polluted water to be missed entirely if they pass downstream beyond the reach of the sample site. Depth variations also return contrasting results, particularly in estuaries and deep-standing bodies of water. The tendency to employ convenient sample sites at accessible locations -- particularly from bridges where abutments may cause turbulence -- is to be avoided.

6. Choice of the Sampler and Sensing Instrument

The two sampling methods available involve either people or machines. Each is subject to failure due to the instrument's reliability. Caprice, perversity and illness are some of the shortcomings of people as sampling instruments. Their behavior patterns may become institutionalized into systematic omissions, as when, for instance, samples are not taken on weekends and holidays, even though waste discharge and water flows are continuous.

How reliable is the alternative of automatic sampling? Robots are subject to equally serious failures caused by the mechanical analogues of caprice, fatigue and breakdown. In addition, robots are subject to vandalism. However attractive automatic sampling may appear -- especially when touted by equipment manufacturers -- recent experience, in our study area and elsewhere, indicates that the state of the art is still too primitive for robots to be entrusted with the responsibility of guarding our waterways (Kerrigan, 1970, panel no. 3). Moreover, robots require backup human support and cannot themselves respond to changing conditions. Though automatic electrochemical monitoring is more reliable than wet chemical methods, the number of parameters that can be analyzed is still limited. We have observed that this rigidity may include the establishment of information bounds, as when the uses of automated instrumentation often confine the parameter set to the variables that can be sensed. Our understanding of water pollution is not sufficiently developed at this time to permit the installation of a rigid instrument package that is also delicate, unreliable and dependent upon human maintenance.

7. Analyzing Samples and Scale Results

Even if all the foregoing requirements are met, the absence of common analytical methods and variable scaling will cause confusion. Intra- and interbasin comparisons are not possible without the use of transformation coefficients. In a metropolitan area where many different agencies are sampling water, disparate analytical methods may introduce errors in the comparison of two data sets.

Sometimes, it may be necessary to change laboratory procedures. To avoid a break in the continuity of the record, the replacement of one method by another should be preceded by a period of time during which the two methods are used simultaneously, in order that transformation coefficients can be derived. We have observed several instances in which coliform methods changed abruptly, causing a break in the data stream.

8. Bookkeeping Practices

Our field experiences revealed that data recording on field sheets and in files differed widely throughout the region in ways that reflected the special interests of the collecting agency, historical events, random choices and indifference on the part of the collection agency. The variation added greatly to the burden of reducing the information to a common format. We recommend strongly that field and office file storage forms be arranged in a uniform format. The raw record should also indicate where breaks occur in the whole file or for particular parameters.

In a metropolitan area water-monitoring scheme, several categories can be established depending on whether the data pertains to sample location and site, agency responsible for collection, political and geographical unit, land use information, ambient parameters, and variables describing inherent water properties. Among the latter variables are those pertaining to hydrology (discharge, stage or surface elevation, velocity), physical properties (color, turbidity, odor), chemical properties (dissolved gases and solids, metals), as well as conductivity, temperature, radioactivity, biochemical attributes, and macro- and microbiological populations, etc. Although no one observation will contain complete information, it is recommended that uniform data sheets be used to record the raw information in format field clusters.

9. Data Storage and Retrieval

Our experience has shown that handling raw data is a three-step process -- the recording of data on field sheets, their manual transfer to files for office storage, and the subsequent assemblage of the accumulated information into a data bank. The first two steps involve intermediate, and, often, temporary data in states of limited accessibility and use. With the accumulation of data sheets, the passage of time enhances the utility of the information. We have observed that lost records and the destruction of files -- by design or through indifference -- are serious obstacles to the compilation of a reliable historic record. It is important, therefore, to aggregate the data into a bank as soon as they have been collected.

The term data bank implies a highly-structured arrangement of information and the ability to identify data receipts and storage. The data bank should have the capability of responding on demand to queries for information on specified accounts and on the state of the whole account for selected time periods -- from the first to the last input. Its organization requires back-sighting to field observations and record keeping, and foresighting to information needs. Hence, it is imperative that the detailed arrangement of each record be linked closely to the sensing instrument and the original field data. Where automatic sensing instruments transmit information by telemetry to a storage bank, the units are, of course, functionally coupled. When field sheets are used, information transfer is facilitated by format compatability between the field sheet and the storage file.

Rapid retrieval of the masses of stored data generated by a metropolitan area water-monitoring system requires the use of punch cards, tapes or disks for machine processing. Data storage should be arranged in simple formats to service the needs of a variety of users and should also be able to satisfy the input needs of software package programs without requiring intermediate output or reformatting. Retrieval difficulties with the EPA's STORET format have already been noted.

In an urban area as hydrologically and managerially diverse as the NYMR, it is useful to think of a data bank composed of two linked modules. The first would contain information about the bank's status, including location by geographical coordinates, political unit, water body address, collecting agency, water intake, treatment, effluent, tax monies, sample frequency, land use and parameters sampled. This would provide a potential user with information about the character of the sample available at a given point and the status of the information system.

The second module, whose files would be linked to the first by a sample identification number, would contain the actual data. This record could be maintained by the collecting agency, while the status record could be housed in a central service organization. Both modules would be open-ended so that new information could be inserted into the record.

10. Systemic Properties of Data

All of the previous elements should be related systemically to form a network of sampling installations that expose water spatial and temporal quality states and patterns for the metropolitan area. To erect the framework, the objectives of the surveillance program must be stated clearly. Raw data generated by the sampling program should be analyzed, scaled and processed in ways that satisfy the objectives. The output should be reviewed against the demands of old and new goals. A feedback loop to the field sampling net should update raw information and prevent the accumulation and collection of useless data.

For system viability, each sample location, site and variable should be related to:

a) all other sample locations and sites
b) all other like variables and selected other variables

c) waste loadings and land uses
d) water uses and water goals

The waterway is a sink for receiving and responding to waste loadings from given land uses and a vector for transmitting the impact of these waste discharges to other water bodies and land uses. The surveillance system must not violate the systemic character of the metropolitan area water environment. In collecting the data for the NYMR taken by a pre-existing monitoring net -- a situation that undoubtedly is found elsewhere -- we have followed a dual framework of hydrologic and geographic hierarchies with a common data base. The former is composed of natural hydrologic elements whose states (historic, contemporary and simulated), are to be defined for selected parameters. The latter hierarchy is imposed on the natural hydrography; it consists of major and minor political divisions whose decisions and policies affect water use and quality goals, land uses and waste loadings (through population, employment, water supply, industry and sewage treatment) and the operations of water agencies. By interfacing the two hierarchies -- the hydrologic and functional -- unity of the metropolitan area water system is preserved.*

F. <u>The Functional Water Institutions</u>

The uses of metropolitan area waterbodies fall into two antagonistic categories: (a) potable, industrial, fishery and recreational uses; (b) sanitary, industrial and runoff disposals. This dichotomy exists for fresh streams, tidal fresh streams, estuaries, lakes, reservoirs and aquifers. As the pressure of urbanism on the water resource grows, the antagonism between the two use categories intensifies.

The manifestation of the conflict and the attempts to ameliorate it take familiar forms. The clean water group employs three strategies: (a) acquisition of new supply sources -- this usually requires going to more distant locations -- horizontally for surface water, vertically for ground water; (b) increased pretreatment prior to use, an option that is not available to in-situ fishery and recreational users; (c) adoption of regulatory and/or punitive measures against the offenders, usually requiring an upgrading of effluent treatment levels.

The spent water group, on the other hand, does not have a corresponding array of strategies available. Its efforts are directed toward encouraging the clean water group to follow options (a) and (b), while attempting to delay the onset of (c) as long as possible. As a last resort they will relocate outfalls at more distant places; this may include moving industrial plants to new sites.

The conflict is anomalous because individuals, municipalities, industries and fisheries have concurrent needs for clean water and effluent disposal. Two circumstances are responsible for externalizing the issues implicit in the antagonistic demands made on the water resource. The first develops

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*A similar but more formal approach to the same question has been developed for Kentucky by WAMIS, the Water Management Information System (Sena, 1970).

within communities when, for some users, the water source is geographically and/or hydrologically separate from the water sink, as, for example, when an industry draws groundwater. It may arise also within communities when the burden of water pretreatment may be shifted to effluent treatment, or vice versa, by vested interests that seek to export or spread their costs.

The second circumstance that exposes the issues stemming from the conflicting water demands of all users is more familiar. It arises when the jurisdictional boundaries imposed on the natural watershed encourage one political unit to export its effluent treatment costs to another unit, where the cost takes the form of higher pretreatment costs or a foregone use.* In a metropolitan area it is important to recognize that equitable water management demands that all costs be regionally internalized to avoid the shirking of responsibility.

Having identified the contending parties and the circumstances under which their interests become manifest, we turn to the question of resolving the conflict in a manner that will be equitable, workable, self-policing and capable of maintaining the quality and utility of the water resource within the constraints of specified goals. The first step is to list the classes of water institutions operating within the NYMR. They are arranged in three classes: clean water users, waste water disposers, and, neutral (no vested interest). Because of the unusual nature of the water resource, an institution may appear more than once.

1. Clean Water Users

    a. Private water companies
    b. Small municipalities or communities
    c. Large public and quasipublic water producers
    d. Industries
    e. Fishery associations
    f. Sport fisheries
    g. Community contact recreation sports
    h. Private contact recreation sports
    i. Marinas

2. Waste Water Disposers

    a. Small municipalities and communities
    b. Large sewerage authorities
    c. Large communities
    d. Industries

3. Neutral

    a. Federal agencies
    b. State agencies
    c. Interstate compact agencies
    d. Scientific research groups

*An excellent example of this cost transfer is provided by the upstream effluent discharge of the Whippany Paper Company and the downstream potable water intakes of the PVWC. The PVWC estimates that it now saves $75,000/year in treatment costs as a consequence of forcing the company to pretreat and re-cycle a portion of its wastes prior to disposal in the Whippany River, a tributary of the Passaic (De Hooge, personal communication, May 1972).

Out of these three groups of institutions, a regional water management structure needs to be fashioned that will administer the coordination of all data collecting, storage, and processing, and the policing of all water users. Its policy directives should derive from a balance of the contending interests.

It is not surprising that the best data we collected were assembled from the records of the private water companies, who have a vested interest in maintaining water quality. The poorest records were kept by sewage plants, with one exception; their exclusive interest is waste disposal, and they often are distinct from water supply operations for the same municipality. Because industry, preferring to ignore the entire question of water disposal, keeps no records, we had to rely on cumbersome estimating methods. Large municipalities with geographically separate and distant protected water sources feel no urgent compulsion to voluntarily upgrade their sewage plants.

The performance of neutral institutions as guardians of water quality leaves much to be desired. Public health departments are more interested in treated and distributed water than in raw water quality, and, thus favor effluent dischargers by default. We often found their record-keeping poor or absent and their performance marked by the issuance of hesitant and confusing abatement notices to secure remedial action by pollution offenders. In many instances, grab sampling was too infrequent to be adequately protective. Capricious funding also limits their effectiveness and makes them vulnerable to pressures.

A policy-making body for regional water management should provide representation for all the above institutions. However, considering the behavioral patterns we have observed and the need to upgrade the quality of the water resource, the membership should be weighted in favor of the clean water users. Amongst these, additional weight should be given to those clean water users who depend on intraregional water sources.

CHAPTER II

SCREENING OF THE HYDROLOGIC DATA: RIVER DATA

The assemblage of the hydrologic data base was a time-consuming and frustrating effort. Though the quality is uneven and, in places, of questionable reliability and accuracy, the data, nevertheless, comprise an impressive array of information on the waters of the New York-New Jersey Metropolitan Region. During the course of the field work, spot reviews of the data eliminated information of obvious low utility. The remainder, after collection and formatting, constitutes a large pool of data that required further screening.

Given the uneven character of the data, our aim was to search out general patterns of variable behavior and associations. We hoped to accomplish several things: (a) to reduce the data mass to more comprehensible dimensions, (b) to observe changes in the state of the hydrologic system and to relate these to changes in urban land use, (c) to note the comparative behavior of the variables in different parts of the region, and, (d) to utilize the understanding of variable behavior thus acquired to construct a predictive water quality model that could assist in the development of policy. In attaining these goals, we were successful within the constraints imposed by data deficiencies.

After a detailed presentation of the analysis of the data bank for each area in which evaluations and suggestions for improvements are made, the question of the significance of raw data collection and interpretation for urban area water management is examined. Our conclusion is that there has been a surprising failure to recognize the contribution that a properly designed monitoring system can make to resource utilization when it is linked to water supply, waste disposal and use goals. The reasons for this failure, the resultant resource use losses, and recommendations for improvements are discussed.

The heavy reliance on chlorination to insure the production of potable water from polluted sources has maintained the viability of urban water systems. Because of its efficacy, chlorination also has been responsible for the irrelevant role of monitoring in water management and the low state of the surveillance art. Given the increasing complexity of life in metropolitan areas and the varied properties of a new generation of pollutants, it is doubtful if chlorination can continue to play the same pivotal role in the future. An alternative is to improve the monitoring net and to integrate it more effectively into the management system. A corollary is the need to rethink the questions of the locations and levels of treatment plants and water use goals.

A. Screening Routines Used

The analysis of the huge volume of data conformed to a general pattern in which the following screening methods were used:

(1) reduction of the data mass to selected central tendency measures (e.g., means)

(2) extraction of factor structures by a principal axes analysis

(3) relation of the factor structures to each other.

Not all data subsets were subjected to all steps. The thoroughness with which each module was examined depended on its suitability for the particular analysis.

Two of the screening routines used -- factor analysis and factor structure relations -- merit a brief description. Factor analysis is a form of multivariate analysis wherein a set of intercorrelated variables is collapsed into a smaller number of composite variables, called factors. The original variables load up on the factors in a way that reflects their intercorrelations. However, the original variables are not distributed uniquely among the factors; their variances are parceled among the factors, but they do show a tendency to load up heavily on one factor. In order to simplify the factor structures, the factors are rotated. Uncorrelated variables retain their independent properties (King, 1969; Rummel, 1970). The factors may be labeled according to their most important original variables.

The factor analyses were performed under conservative assumptions. Communalities (a statistical measure of common association of variables) were estimated by using the squares of the multiple correlation coefficients between each variable and all other variables in the data set. The communalities appear along the principal diagonal of the correlation matrix. Alternative estimates of the communality could have been chosen; for example, ones could be inserted in the principal diagonal. This procedure then assumes that all of the variance of each variable is related to the common factors of the data set. The true communality presumably lies between the multiple correlation coefficient and unity estimates; thus, our estimate is more realistic.

The factor analysis algorithm extracted a set of factors by the principal axes method. These factors are then rotated so as to concentrate the loadings on a few of the factors. The rotation used was the Varimax solution, which involves a series of orthogonal transformations of factor pairs.*

Rotations were performed initially on factors only if the eigenvalues were equal to or greater than unity. In most cases, this rule ensured that each rotated factor accounted for at least 5% of the total variance, and ruled out spurious factors. In order to ensure uniformity among factor structures on some data sets, several factor analyses were performed with a stipulated number of factors to be rotated. In runs where only one factor with an eigenvalue ≥ 1.0 was available, a factor with a value ≥ 0.75 was rotated. Rotation usually improved the explanatory power of these factors. Final communalities on the variables also were obtained. These, together with the total variance explanation accounted for by factors with eigenvalues ≥ 1.0, indicated the suitability of the factor analytic model.

Another screening routine was the comparison of the factor structures from two different data sets. This analysis requires as input the factor-loading matrices that were obtained from a factor analysis of identical sets of variables. The factor axes are rotated until maximum overlap between corresponding test vectors in the two structures is attained. The

*The program used is described by Dixon (1967), modified to give rotated factor structures.

degree of rotation required is expressed as the cosine of the angle between the factor axes. These cosines squared may now be interpreted as correlations between the factors.*

The comparison of factor structures requires identical sets of variables arrayed in the same order. Thus, it can only be used with those data sets that had the same variables over a sufficient period of time. In essence, this constraint practically eliminated interbasin comparison of factor structures, given the nonconformality of the data bank. The only solution is to use reduced sets of variables; but questions of meaningful interpretation arise.

The data on the sewage treatment plants required different procedures. Given the spotty reporting, recording and storing of effluent data, a rigorous statistical analysis would not have been appropriate. Consequently a frequency distribution of the number and size of treatment plants arranged logarithmically was made. In addition, a discussion of some of the larger regional plants and related growth trends will be considered.

B. New Jersey

The information collected on the water bodies of New Jersey turned out to be the most useful, and they were submitted to intense analysis. The data were assembled by collecting agency and water body as follows:

1. Elizabethtown Water Company (EWC)

    Raritan River
    Millstone River
    Delaware and Raritan Canal

2. Environmental Protection Agency (EPA)

    Raritan River

3. Passaic Valley Water Commission

    Passaic River

4. Hackensack Water Company

    Hackensack River

1. Elizabethtown Water Company (EWC)

As stated in the previous chapter, EWC samples raw water on a daily, weekly and monthly basis at each of three intakes at the confluence of the Raritan and Millstone Rivers in central New Jersey. With the addition

*The program used is described in Veldman (1967) under the name, RELATE, slightly modified.

of discharge and percent saturation, the best mix of frequency of observation and total number of variables is reached with the weekly series. Accordingly, a statistical summation of secular trends in selected variables was made.

The average annual means and standard deviations for DO for the three intakes are shown in Figures 1 and 2. The improvement in the mean DO for the Raritan may be partially attributed to flow augmentation. Spruce Run Reservoir with a storage capacity of 11 billion gallons was completed in October 1963 in the headwaters of the South Branch of the Raritan. Spruce Run is an on-stream reservoir in contrast to Round Valley Reservoir which requires pumpage of river water to fill its 55 billion gallon capacity. The latter, completed in March 1966, is the largest reservoir in New Jersey. In comparison, Wanaque Reservoir has a storage capacity of 28 billion gallons.

The Millstone mean DO values are the lowest of the three intakes. The mean DO values for the Canal are not only high but exhibit the least variation, as is evidenced by examining the standard deviation values (Figure 1). This minimal variation is explained by the regulated flow of the Canal as compared to the more "free flowing" Raritan and Millstone Rivers.*

By virtue of a U.S. Supreme Court decision in 1954, New Jersey can divert up to 100 mgd of raw water from the Delaware at Raven Rock, a point 20 miles upstream of Trenton (New Jersey, Commission on Efficiency, p. 43). The water then flows via the canal by gravity through 55 miles of central New Jersey. Unmeasured spill from the Canal is released into the tidal Raritan at New Brunswick.

The Millstone River rises in the Coastal Plain Province, flows into Lake Carnegie (an artificial lake) and then flows northward through the Piedmont Province where it joins the Raritan near Bound Brook. The drainage area is over 260 square miles and the length of the main channel exceeds 28 miles. The average discharge for the 49 years of record from 1921 to 1970 is 356 cfs, or 1.38 cfs/square mile.

The Raritan River rises in the Highlands of New Jersey and then flows eastward through the Piedmont Province. The total length of the Raritan is over 74 miles, with the tidal portion accounting for 19 miles (26%). The drainage area just above the confluence with the Millstone is 490 square miles. The average unadjusted discharge for 52 years (1903-06, 1921-70) is 716 cfs, or 1.46 cfs/square mile.

Average annual hardness values are shown in Figure 3. Note that hardness for all three intakes peaks in 1965, the worst year of the drought. The trend of the curves suggests an inverse relationship between hardness and discharge. The highest and lowest values were consistently recorded for the Raritan and Canal, respectively.

*A note of caution is in order here. A recent USGS open-file report (McCall and Lendo, 1970) states that all of the larger streams in New Jersey are affected by regulation and/or diversion. Consequently, the term "free flowing" is used only in a broadly descriptive manner. For example, the USGS does not publish monthly and annual discharge/square mile values for the Raritan River at the Manville and Bound Brook gages because of extensive regulation and diversion (USGS, Surface Water Records, 1969).

FIGURE 1.
ELIZABETHTOWN WATER COMPANY
DO STANDARD DEVIATIONS

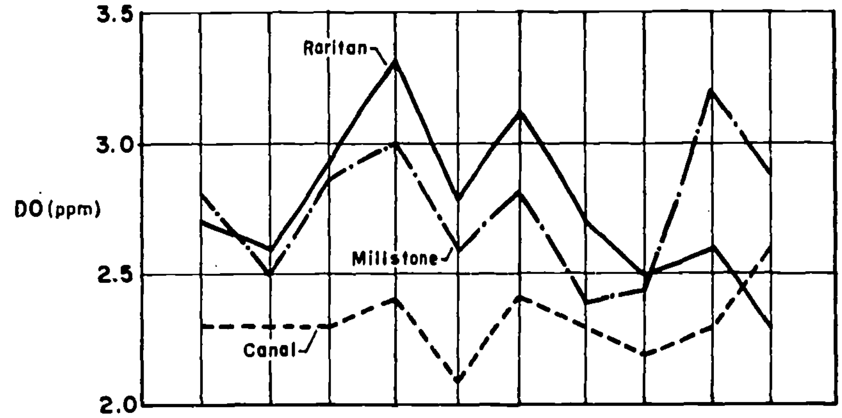


FIGURE 2.
ELIZABETHTOWN WATER COMPANY
DO MEANS

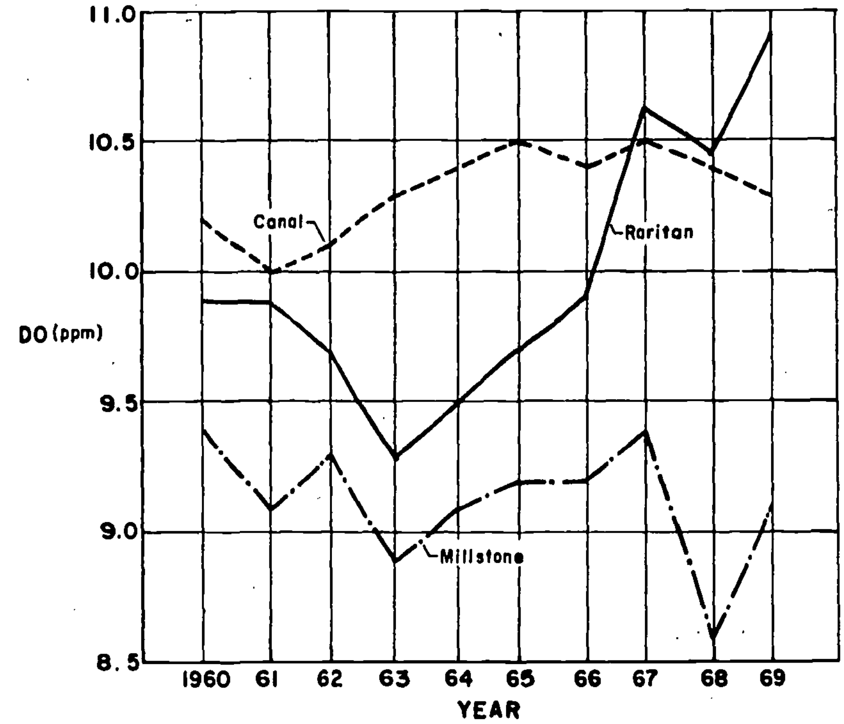


FIGURE 3.
ELIZABETHTOWN WATER COMPANY
(HARDNESS)

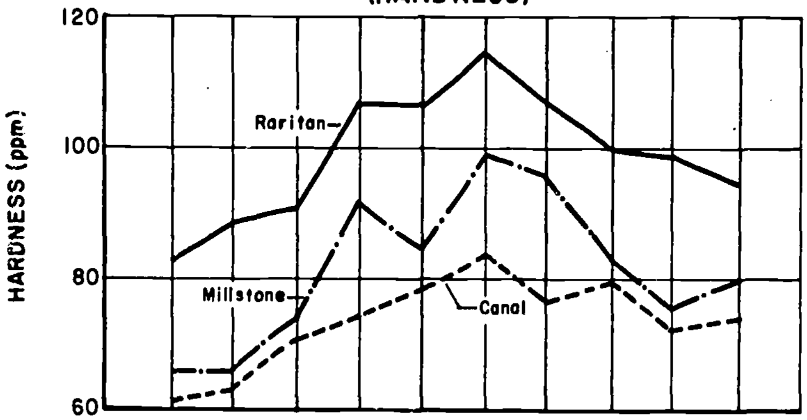


FIGURE 4.
ELIZABETHTOWN WATER COMPANY
(BACTERIA)

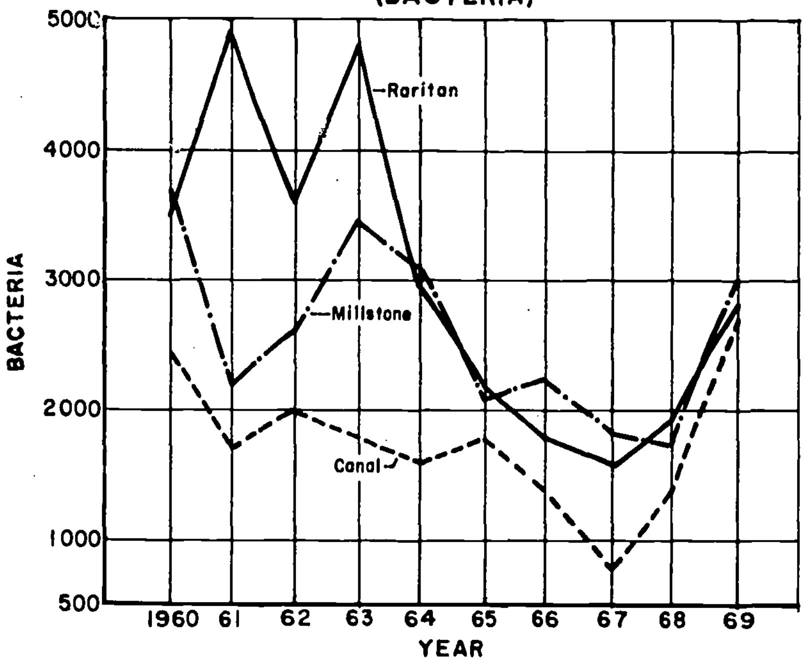


Figure 4 shows average annual bacteria levels. The Raritan has the highest values, but there is some improvement during the decade. Note that the Canal bacteria levels are consistently below those of the Raritan and Millstone.

Some of the variations indicated in Figures 1-4 can be attributed to the natural characteristics of each basin. For example, the variations between coastal plain and noncoastal plain streams is to be expected based upon differing geohydrology. Also, Canal water is coming from a basin of approximately 6,350 square miles, whereas the Raritan and Millstone drain areas of 490 and 260 square miles, respectively. Smaller basins exhibit wider variation of water quality parameters.

McCall and Lendo (1970) have summarized some of the characteristics of drainage basins for New Jersey. Specifically, the Raritan at the Manville gage has an average slope of 12.1 feet/mile and is 40% forested, whereas the Millstone at the Blackwells Mills gage has an average slope of 3.8 feet/mile and is 35% forested.

The degree of urbanization of a basin has obvious ramifications. Subsumed under the term urbanization are treatment levels of sewage plants, proportion of population sewered, degree of impervious cover, and so on. One recent engineering report by Elson T. Killam Associates (1970) estimates the combined flow of all treatment plants in the Raritan above the Millstone confluence to be 17.1 cfs (11 mgd), or only 2.4% of the average discharge of 716 cfs. Comparable figures for the Millstone are 15.5 cfs (10 mgd), or 4.4% of the average discharge of 356 cfs. It is worth noting here that these proportions are considerably less than those recorded for the Passaic basin.

The weekly series of observations at the three EWC intake sites (Raritan, Millstone and the Delaware and Raritan Canal) consists of nine variables collected by EWC (temperature, pH, DO, turbidity, BOD, color, alkalinity, hardness, and bacteria), one variable obtained from USGS records (discharge), and one variable derived from temperature and DO (percent saturation). The ten years of weekly observations comprise nearly 5,720 bits of information at each site, or over 17,000 bits of information for the three sites. In order to reduce this volume of information to more manageable proportions, the data sets were subjected to factor analysis.

The first set of factor analyses on the 11 variables revealed two or three factors, using the multiple correlation coefficient in the diagonal and an eigenvalue cutoff of 1.0 for rotation. In order to ensure uniformity from year to year, the factor analyses were performed again, this time specifying that three factors were to be rotated. The following discussion is based on the ordered three factor models.

As shown in Table 1, the weekly series of observations on the Canal forms three characteristic factors, namely, an oxygen-status factor (temperature, DO, and BOD), an appearance factor (turbidity and color), and a third factor usually consisting solely of percent saturation. Several features from Table 1 can be delineated.

a. The cumulative percentage of explanation for the Canal declines from a high of 69% in 1960 to a low of 54% in 1969. Although the decline is not steady from year to year, a perceptible secular decrease in explanation is apparent.

b. The highest loadings are almost always associated with temperature, DO, and percent saturation. On the other hand, bacteria, hardness, and pH exhibit low loadings in the factor structures. Indeed, bacteria appears to be unrelated to any of the other variables in the set.

c. Temperature and DO show inverse factor loadings, which is in accord with theory.

d. Discharge tends to be associated with the oxygen-status factor, but in some years this relationship is minimal and in other years, discharge splits between two and even three factors (1961 and 1965).

e. The oxygen-status factor is generally the most important factor, based on its proportion of the total explanation. In most years it accounts for nearly one-half of the cumulative explanation.

f. 1965 represents an unusual year -- the usual temperature-DO relationship breaks down. Although the correlation coefficient for that year is -.81, the two variables are not in the same factor. Presumably, this anomaly was caused by drought conditions, as 1965 was the driest year in the 1962-66 drought.

Factor analysis of the Millstone data sets also yields an oxygen-status factor, an appearance factor, and a saturation factor. As indicated in Table 2, the Millstone factor structures are broadly similar to those of the Canal, but there are some differences:

a. High factor loadings show up on temperature and DO, and in addition, on turbidity and color. Indeed, the decade mean factor loading for turbidity and color is .75 and .80 for the Canal and .85 and .85 for the Millstone. This can be interpreted as an indication that the appearance factor is more statistically important on the Millstone.

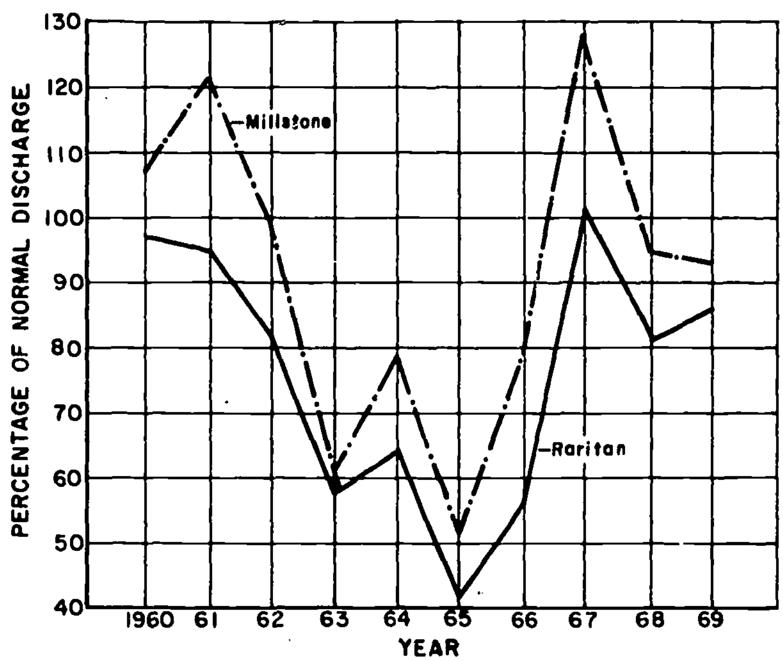
b. The cumulative percentage of explanation decreases from 77% in 1960 to 60% in 1969. Although the decade mean cumulative explanation for the Millstone of 67% is greater than that of the Canal (60%), the same secular decrease in the explanatory power of the model is seen.

Table 1. Delaware and Raritan Canal
Rotated Factor Structures
(EWC data, weekly obs.)

Year	Factor	% Expl.	Temp	DO	BOD	pH	Alk.	Q	Turb.	Color	Hard-ness	% Sat.
	I	30	-.92	.85	.76	-		-.69			.72	
	II	24					.76		-.77	-.80		
1960	III	15										.94
	All	69										
	I	25					-.82	.45	.82	.76	-	
	II	27	-.96	.98	.63	-		.36				
1961	III	10										.89
	All	62										
	I	39	.97	-.90	-.35	.74	.91	.75			-	
	II	16							-.86	-.85		
1962	III	11										-.89
	All	66										
	I	28	.95	-.95	-.51	-	.65	.61			-	
	II	16							-.88	-.89		
1963	III	13										.93
	All	57										
	I	34	.98	-.92	-.60	.66	.67	.80			-	
	II	17					.62		-.60	-.70		
1964	III	11										.93
	All	62										
	I	22		-.85	-.66			.15			-	-.95
	II	16						-.19	.85	.88		
1965	III	20	.82			.71	.62	.16				
	All	58										
	I	25	.87	-.98	-.80	-					-	
	II	16					.69	.28	-.60	-.73		
1966	III	15										-.78
	All	56										
	I	30	-.92	.92	.75	-	-.64	.62			-	
	II	19							.73	.89		
1967	III	13										.97
	All	62										
	I	24	.91	-.97	-.49	-					-	
	II	18						.30	.75	-.79		
1968	III	13										.97
	All	55										
	I	16					.61		-.64	-.67	-	
	II	15						-.45				.94
1969	III	23	-.93	.86	.70							
	All	54										

FIGURE 5.

DISCHARGE OF MILLSTONE AND RARITAN RIVERS
AS A PERCENTAGE OF LONG TERM ANNUAL FLOWS
1960-1969



c. Although the temperature-DO relationship holds for most of the decade (1960-62, 1964, 1966-69), the association in the same factor is severed in 1963 and 1965. Also, the DO variable splits between two factors during 1967-69, as shown in Table 2.

d. Discharge is usually associated with the appearance factor (1960-62, 1966-69), but it splits among three factors in 1964 and associates with a temperature factor in 1963 and 1965. Again, the mid-1960s represent the marked decrease in precipitation in the northeast.

Figure 5 expresses the average annual discharge of the Millstone and Raritan Rivers as a percentage of the long-term mean flows, recalculated for each year. Thus, the 1960 and 1969 percentage of normal discharge for the Millstone and Raritan is based on 40 and 43 years, and 48 and 51 years of record, respectively.

According to the State Climatologist of New Jersey (Dunlap, 1968), the drought in New Jersey lasted for a record 60 consecutive months; from October 1962 to October 1966. As shown in Figure 5, The Millstone and Raritan Rivers responded by declining in 1965 to less than half of normal streamflow. This sharp decrease accounts then for some of the variations in the factor structures during the decade.

Table 3 shows the annual factor structures for the Raritan River. Again, similar interpretations can be made, namely, (a) high loadings on the temperature-DO and appearance factors; (b) a decrease in cumulative percentage of explanation from 72% in 1960 to 59% in 1969; and (c) a splitting of the discharge variable among two or three factors during 1962-64.

Several differences can be indicated in Table 3, however. For example, bacteria appear on the Raritan for six years out of the decade with factor loadings greater than .50. This is attributed to the larger amounts of bacteria recorded in the stream, as depicted in Figure 4. Another way of looking at bacteria in the factor structures is to examine the communalities. The higher the communality, the greater the relationship of the variable to the factors. Conversely, low communalities can be interpreted as an indication that the variable is independent and unrelated to the other variables. Indeed, the inclusion of many variables with low communalities could actually reduce the explanatory power of the factor analytic model by introducing more noise than signal.

In the EWC samples, the decade mean communalities for bacteria were 0.14, 0.38, and 0.41 for the Canal, Millstone, and Raritan, respectively. Thus, bacteria is most associated (albeit weakly) with the other variables in the Raritan and least in the case of the Canal.

It is appropriate at this juncture to consider the extent of flow augmentation in the Raritan Basin. Spruce Run Reservoir was completed in October 1963 with a usable capacity of 11 billion gallons (USGS, Surface Water Records, 1969). Water is released from the reservoir to maintain a State-imposed minimum flow of 90 mgd at the Bound Brook gage downstream.

Table 2. Millstone River
Rotated Factor Structures
(EWC data, weekly obs.)

Year	Factor	% Expl.	Temp.	DO	BOD	ph	Alk.	Q	Turb.	Color	Hard-ness	% Sat.	Bact.
	I	34	-.93	.99	.69		-.67					.84	
	II	31						.80	.97	.96			.75
1960	III	12				.64							
	All	77											
	I	33	-.97	.92	.75	-.69							
	II	28						.82	.86	.88	-.66		
1961	III	12										-.84	
	All	73											
	I	34	-.89	.99	.58		-.68					.92	
	II	26						.79	.89	.94			
1962	III	10				-.76							
	All	70											
	I	25	.71		-.55	.79	.74	-.63					
	II	23							.96	.98			.72
1963	III	25		.88								.96	
	All	73											
	I	29	.95	-.77	-.71	.76	.63	-.33					
	II	23						-.29	-.88	-.94			-.73
1964	III	19						.47			-.71	.86	
	All	71											
	I	21	-.81					.51					-.64
	II	24		.87	.74							.97	
1965	III	12							.73	.66			
	All	57											
	I	29				.71	.67	-.85	-.79	-.71			
	II	26	-.99	.90	.56								
1966	III	12										-.87	
	All	67											
	I	26	.91	-.72	-.70		.66						
	II	25						-.65	-.85	-.75			
1967	III	13		.66								.97	
	All	64											
	I	20	.86	-.65			.69						
	II	24				-.61		.64	.64	.89			
1968	III	18		-.74	-.64							-.91	
	All	62											
	I	22	-.93	.72	.52		-.64						
1969	II	24						.89	.91	.81			
	III	14		.68								.96	
	All	60											

Table 3. Raritan River
Rotated Factor Structures
(EWC data, weekly obs.)

Year	Factor	% Expl.	Temp.	DO	BOD	pH	Alk.	Q	Turb.	Color	Hard-ness	% Sat.	Bact.
	I	29	-.93	.85	.69								
	II	28						.75	.89	.94			.61
1960	III	15										-.82	
	All	72											
	I	24					-.89	.61			-.81		
	II	27	.89	-.94	-.50							-.79	
1961	III	18							.84	.87			
	All	69											
	I	32	-.75	.81			-.76	.57			-.78	.79	
	II	25						.60	.89	.95			
1962	III	12	-.52	.55	.62								
	All	69											
	I	40	.90	-.94	-.75		.84	-.48			.74	-.75	
	II	21						.51	.95	.97			
1963	III	11				.51		-.40				.60	-.53
	All	72											
	I	32	.95	-.98	-.62			-.36				-.83	
	II	22						-.36	-.86	-.88			-.80
1964	III	16					-.80	.26			-.85		
	All	70											
	I	33	-.90	.97	.84							.83	
	II	14							-.82	-.85			
1965	III	18					.83	-.65			.78		
	All	65											
	I	31	-.94	.99	.78							.84	
	II	21				-.70	-.82	.64			-.61		
1966	III	19							-.86	-.85			-.58
	All	71											
	I	24							.94	.88		.84	
	II	25	.93	-.98	-.71								
1967	III	18					.71	-.85					-.66
	All	67											
	I	21	.75	-.63					.62	.71			.54
	II	28				.80	.80	-.61	-.51	-.49	.71		
1968	III	16		-.65	-.48							-.90	
	All	65											
	I	24	-.94	.94	.74								
	II	24						-.88	-.78	-.81			
1969	III	11										-.91	
	All	59											

Water from Spruce Run is stored in Round Valley Reservoir with a storage capacity of 55 billion gallons. Interestingly, this massive reservoir has release constraints up to a maximum of 20 mgd -- the greatest amount the natural channels leading from the reservoir can take without damage. One wonders why a pumped storage scheme was not put into effect, as almost all water must be pumped up into Round Valley from the South Branch of the Raritan. The pumping costs at the Hamden pumping plant are considerable (Chase, personal communication).

Table 4 shows the proportionate contribution of discharge for two downstream gaging stations on the Raritan that is accounted for by the Spruce Run watershed. The gage at Stanton on the South Branch is two miles downstream of Spruce Run, while the Manville gage is 25 miles downstream and also receives the flow of the North Branch of the Raritan.

As indicated in Table 4, Spruce Run water accounts for about the same proportion of the downstream flows during the prereservoir period (1960-62) as during the pastreservoir period (1965-66). Thus, one may conclude that flow augmentation was unimportant if one looks only at average annual values. However, if we examine the record for the summer months of June-September, the extent of flow augmentation becomes pronounced. Consequently, Spruce Run water did improve water quality on the Raritan, particularly during the drought.

Table 4. The Proportionate Contribution of Discharge to the Raritan Basin by the Spruce Run Watershed[a]

Time Period	Stanton gage[b]	Manville gage[c]
1960-62 Annual	27.5%	8.6%
1965-66 Annual	23.1	9.4
1960-62 Summer[d]	24.3	9.4
1965-66 Summer	64.6	22.2

[a] 1963-64 was not included because the reservoir was filling during this period.

[b] drainage area of 147 square miles

[c] drainage area of 490 square miles

[d] Summer months of June, July, August and September

In summary, the factor structures of the EWC sampling intakes reveal the following characteristics:

a. The 30 annual factor structures for the three intakes generally indicate three factors: an oxygen-status factor (high loadings on temperature, DO and BOD), an appearance factor (turbidity, color and discharge), and a third variable factor usually based on percent saturation.

b. The cumulative percentage of explanation for all three intakes declined during the decade, suggesting an interference in in-stream interactions among the variables. It is hypothesized that human interference might be the causative agent, in the form of increased effluent discharges and accelerated runoff commensurate with urbanization and land use changes. Although the dictates of research time preclude further investigation of this point, it would be interesting to extend the factor analyses back into the decade of the 1950s in order to substantiate the urbanization hypothesis. The simulation model of the Raritan which is discussed later does provide some material to test the hypothesis.

c. Hardness, bacteria and pH are generally the least important of the 11 variables used in the factor analytic model. Factor loadings are generally lower than .70, which is a conservative threshold for importance in the model.

d. Of the three factors, the oxygen-status factor is generally the most important in terms of explanation. The decade grand mean explanation for this factor is 43%, as compared to 33% for the appearance factor.

Factor Structure Comparisons

In order to assess intra-basin and inter-basin changes in watershed characteristics, the EWC factor structures were compared in space and over time. As mentioned previously, the computer program RELATE (Veldman, 1967) quantitatively compares one factor structure with another as long as the variables are the same and remain in identical order.

RELATE enables one to indicate the degree of similarity between factor structures by obtaining the cosine of the angle between component vectors. These cosine values may then be interpreted as correlation coefficients. Perfect identity in the comparisons would be denoted by an identity matrix I with ones in the principal diagonal. Hughes (1971) used RELATE in his study of major urban metropolitan systems. As Hughes states, "The greater the value of the off diagonal, the greater the difference between the corresponding factors."*

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*Hughes, J. W., 1971. Equifinality in major urban metropolitan systems: a cross-cultural factor analytic study. Unpublished Ph.D. dissertation, Rutgers University.

Table 5 shows the highest cosine values for the factor structures for consecutive years for each waterway. The values can be interpreted in a manner similar to correlation coefficients. Thus, a value of 1.0 would indicate a perfect match between the factors and 0.0 would show no association. Any other value between 0.0 and 1.0 would be a measure of the degree of association between factor structures.

The Canal provides the best year-to-year comparisons. As shown in Table 5, the mean value for all pairs of years exceeds .80. Indeed, only once during the decade (1965-66) did the mean cosine value fall as low as .81. For five of the nine periods of comparison (1960-61, 1962-63, 1963-64, 1966-67, and 1967-68), the mean value was greater than or equal to .95. The decade grand mean was .93, exceeding the values of .91 and .87 for the Millstone and Raritan, respectively. Thus, the Canal provides the most consistent set of factor structures of the three intakes.

The Raritan structures show the lowest year-to-year comparisons. Note the .71 and .79 mean values for 1960-61, and 1962-63 and 1967-68 (Table 5). Interestingly, the peak mean values of .99 for 1964-65 and 1965-66 contrast markedly with the same periods for the Canal, when decade minimums were reached. Presumably, the flow augmentation on the Raritan accounts for the disparity between the two stations. The decade grand mean of .87 is the lowest of the EWC stations.

The Millstone values are intermediate among those of the Canal and Raritan. The lowest mean value of .80 was reached in 1961-62, whereas higher values were attained in the latter part of the decade. In three years out of the nine, mean values were equal to or greater than .95 (see Table 5).

Summarizing, although there is some variation in year-to-year factor comparisons among the three sets, the dominant theme is one of factor stability over time. That is, the similarities from year to year are greater than the differences. Thus, the results from the structure comparison support our earlier finding of two and sometimes three characteristic multivariate water quality factors.

The year-to-year degree of association between the factor variables is given in Table 6. These values identify the specific contribution of each variable to the overall correspondence between factors. The most consistent variables for the Canal are temperature, DO and percent saturation, as the decade mean coefficients are all equal to or greater than .97. Alkalinity, hardness and bacteria are the most erratic performers during the decade, with mean coefficients of .77, .72 and .65, respectively. Temperature, DO and percent saturation always report high factor loadings during the decade on the Canal (Table 1).

The year-to-year mean correlations on the Canal ranged from a low of .81 in 1968-69 to a high of .95 in 1962-63. The decade average was .87, providing another indication of high variable consistency (Table 6).

Table 6 shows that temperature and DO coefficients were high for the Millstone, an observation in accord with the Canal results. Similarly, hardness and bacteria had low coefficients (.72 and .66), and in addition, BOD shows a decade mean coefficient of .72. The year-to-year grandmean of .88 is practically the same as that of the other stations.

Table 5. Year-to-Year Factor Structure Comparisons Within the Canal, Millstone, and the Raritan, 1960-1969. (Highest Cosine Values Used. EWC Data Set.)

Waterway	Year	Factor I	Factor II	Factor III	Mean
A. Canal	1960-61	.93	.98	.95	.95
	1961-62	.91	.91	.99	.94
	1962-63	.96	.99	.97	.97
	1963-64	.92	.94	.98	.95
	1964-65	.84	.84	.99	.89
	1965-66	.74	.95	.73	.81
	1966-67	.90	.95	.99	.95
	1967-68	1.00	.98	.99	.99
	1968-69	.92	.90	.85	.89
	Mean	.90	.94	.94	.93
B. Millstone	1960-61	.97	.86	.83	.89
	1961-62	.72	.97	.72	.80
	1962-63	.86	.87	.95	.89
	1963-64	.98	.96	.98	.97
	1964-65	.91	.95	.96	.94
	1965-66	.92	.77	.83	.84
	1966-67	.92	.92	.97	.94
	1967-68	.95	.93	.98	.95
	1968-69	.98	1.00	.98	.99
	Mean	.91	.91	.91	.91
C. Raritan	1960-61	.65	.82	.67	.71
	1961-62	.83	.83	.81	.82
	1962-63	.85	.83	.70	.79
	1963-64	.86	.95	.84	.88
	1964-65	.98	.99	.99	.99
	1965-66	1.00	.99	.99	.99
	1966-67	.96	.96	.98	.97
	1967-68	.95	.74	.69	.79
	1968-69	.85	.81	.95	.87
	Mean	.88	.88	.85	.87

Table 6. Year-to-Year Variable Correlations on Factors Extracted for the Canal, Millstone and Raritan, 1960-69. (EWC data set)

	Year	Temp	pH	DO	Turb	BOD	Color	Alk	Hard	Bact	Q	Sat.	Mean
A. Canal	1960-61	.98	.95	1.0	.97	.89	.84	.98	.41	.55	-.83	.99	.85
	1961-62	.96	.99	.98	.93	.75	.98	.83	.50	.98	-.82	.99	.89
	1962-63	.99	.87	.98	.99	.96	.99	1.00	.90	.82	.95	.97	.95
	1963-64	.93	.89	.95	.96	.92	.98	.96	.49	.67	.88	1.0	.88
	1964-65	1.0	.86	.99	.91	1.0	.98	.39	.95	.75	.68	.93	.86
	1965-66	.99	.85	.96	.66	.97	.92	.07	.92	.92	1.0	.99	.84
	1966-67	.98	.94	.93	.92	.90	1.0	.72	.54	.21	-.96	.97	.83
	1967-68	1.0	.97	.99	.94	.96	.95	.99	.99	.82	-.69	1.0	.94
	1968-69	.99	.99	.99	.89	.85	.85	.96	.81	-.10	.56	.89	.81
	Mean	.98	.92	.98	.91	.91	.94	.77	.72	.65	.82	.97	.87
B. Millstone	1960-61	.95	.37	.99	.93	.82	.88	1.0	.86	.45	.99	.64	.81
	1961-62	.93	.86	.96	.94	.82	.99	.93	.94	.80	.99	1.0	.92
	1962-63	.99	.96	.97	.94	.94	.95	1.0	.75	.99	.90	.97	.94
	1963-64	.89	.98	.93	.92	.94	.98	.95	.75	.97	.89	.98	.93
	1964-65	.99	1.0	.99	.94	.65	.92	.93	.54	.36	.85	1.0	.83
	1965-66	.94	.94	.96	.99	.53	.93	.92	.77	.09	.86	.97	.81
	1966-67	.99	.99	1.0	.86	.99	.98	.96	.55	.87	.98	.99	.93
	1967-68	1.0	.94	1.0	.97	.36	.97	.96	.90	.96	.92	.94	.90
	1968-69	.99	.85	1.0	.88	.43	.97	.99	.37	.46	.94	.98	.81
	Mean	.98	.88	.98	.93	.72	.95	.96	.72	.66	.93	.94	.88
C. Raritan	1960-61	.99	1.0	.99	.87	.87	.83	.87	.55	.98	.99	.87	.89
	1961-62	.99	.72	.99	.97	.57	.94	.98	.95	.65	.97	.81	.87
	1962-63	1.0	.89	.96	.90	.65	.91	.89	.82	.98	.93	.85	.89
	1963-64	.88	.59	.99	.96	.94	.92	.95	.66	.75	.97	.88	.86
	1964-65	.97	.50	.99	.96	.90	.92	1.0	.97	.81	.78	.99	.89
	1965-66	.99	.83	.99	1.0	.90	.94	.96	.93	.89	.89	.86	.93
	1966-67	.87	.97	.99	.97	.96	.93	.95	.80	.90	.81	.62	.89
	1967-68	.99	.96	.98	.79	.96	.92	.93	.86	.65	.98	.89	.90
	1968-69	.93	1.0	.99	.86	.73	.91	.96	.60	.78	.91	.98	.88
	Mean	.96	.83	.99	.92	.83	.91	.94	.79	.82	.92	.86	.89

The variable set on the Raritan generally shows the highest consistency from year to year. Note in Table 6 that all variable decade means are equal to or greater than .79, with temperature and DO again leading the set. The year to year means on the Raritan range from .86 in 1963-64 to a high of .93 in 1965-66. This range of .07 is half that of the range on the Canal (.95 - .81 = .14) and Millstone (.94 - .81 = .13).

Summarizing, the associations in Table 6 indicate that most variables are highly consistent from year to year. The more erratic variables are hardness, bacteria and occasionally BOD. Temperature and DO invariably head the list in terms of consistency.

Turning now to interbasin factor comparisons within the entire Raritan watershed, we find in Table 7 that the Canal is structurally quite similar to the Millstone. This is surprising, because Canal water is really Delaware River water which is coming from a basin about 25 times as large as the Millstone. The mean cosine value varies from a low of .75 in 1960 to a high of .99 in 1965, averaging .89 for the decade. There is noticeable fluctuation from year to year, but the associations remain strong.

Structural congruence between the Canal and Raritan exists, but at a lower level (see Table 7). For three years in the decade, the mean cosine value is less than or equal to .75. The overall decade mean drops to .84, as compared to .89 for the Canal and Millstone. Thus, we may conclude that even though the Canal water is coming from a different basin, the factor structures on the Canal are similar to those of the Millstone and Raritan.

As shown in Table 7, the factor structures between the Millstone and Raritan are strongly associated. In only one year (1967) did the mean cosine value drop as low as .75. For seven years out of the decade, the mean values were equal to or greater than .90. This structural similarity is to be expected, in view of the fact that both streams are major tributaries within the same basin.

The variable associations between factors given in Table 8 support the previously-discussed findings. In particular, the decade grand mean coefficient for all variables for the Canal and Millstone of .90 is greater than the comparable figure of .84 for the Canal and Raritan. The mean value for the Canal and Millstone varies from .81 in 1960 to .96 in 1969. This range of .15 is similar to that of the Canal and Raritan, except that the high and low values are recorded as .74 in 1965 and .91 in 1961.

The lowest decade mean values in Table 8 are reported for discharge. Presumably, the highly regulated flow of the Canal with its commensurate minimal variance stands out in contrast to the more skewed distributions of flow on the Millstone and Raritan. Consequently, the low coefficients for discharge are predictable.

As discussed previously, the Millstone and Raritan evidence structural similarities. Table 8 shows the high coefficients for temperature, DO and discharge. Only pH and percent saturation have decade mean values less than .80. Reading across the rows of Table 7, one notes the low mean value of .72 for 1965, a year which witnessed the commencement of flow augmentation on the Raritan. In all other years of the decade, the values equaled or exceeded .85.

Table 7. Interbasin Factor Structure Correlations with the Raritan Watershed, 1960-69. (EWC data set)

Basin Pairs	Year	Factor I	Cosine Value Factor II	Factor III	Mean
A. Canal and Millstone	1960	.77	.77	.72	.75
	1961	.99	.98	.97	.98
	1962	.80	1.0	.80	.87
	1963	.77	.63	.99	.80
	1964	.93	.88	.94	.92
	1965	1.0	.99	.99	.99
	1966	.85	.96	.85	.87
	1967	.94	1.0	.94	.95
	1968	.96	.76	.74	.82
	1969	1.0	.96	.95	.97
	Mean	.90	.89	.89	.89
B. Canal and Raritan	1960	.87	.81	.89	.86
	1961	.84	.66	.75	.75
	1962	.77	.98	.78	.84
	1963	.99	.95	.94	.96
	1964	.72	.77	.62	.70
	1965	.94	.93	.99	.95
	1966	.98	.90	.89	.92
	1967	.91	.71	.65	.78
	1968	.66	.70	.69	.68
	1969	.89	.99	.88	.92
	Mean	.86	.84	.81	.84
C. Millstone and Raritan	1960	.94	.89	.90	.91
	1961	1.0	1.0	.76	.92
	1962	.94	.96	.93	.94
	1963	.72	.96	.74	.81
	1964	.98	.98	.99	.98
	1965	.93	.89	.91	.91
	1966	.99	.76	.76	.84
	1967	.78	.74	.73	.75
	1968	.87	.87	1.0	.91
	1969	.92	.93	.85	.90
	Mean	.91	.90	.86	.89

Table 8. Year to Year Interbasin Variable Correlations on Factors Extracted for the Canal, Millstone and Raritan, 1960-69 (EWC data set)

	Year	Temp	pH	DO	Turb	BOD	Color	Alk.	Hard	Bact	Q	Sat.	Mean
A. Canal and Millstone	1960	.82	.50	.96	.83	.90	.89	.92	.92	.95	-.74	.50	.81
	1961	.99	.89	1.0	.97	.98	.99	.91	.92	.99	.89	.86	.94
	1962	.98	.87	.98	.98	1.0	.98	.98	.67	.85	-.48	.89	.88
	1963	.97	.96	.98	.94	.96	.95	.99	.94	1.0	-.86	.88	.95
	1964	.96	.98	.91	.99	.87	.97	.94	.53	.65	-.29	.87	.82
	1965	.99	.96	1.0	.86	.93	.91	.75	.98	.43	-.95	.99	.89
	1966	.97	.96	.95	.99	.80	.85	.93	.99	.85	-.75	.96	.91
	1967	.97	.95	.99	.98	.87	.94	.95	.98	.97	.83	.93	.94
	1968	.99	.93	.99	.97	.83	.99	.97	.93	.85	-.68	.68	.89
	1969	.98	.99	.99	.98	.99	.98	.89	.61	.97	.27	.90	.96
	Mean	.96	.90	.98	.95	.91	.94	.92	.85	.85	.67	.85	.90
B. Canal and Raritan	1960	.85	.78	.94	.97	.84	.92	.89	.53	.89	-.42	.86	.81
	1961	.92	.97	.98	.92	.99	.94	.89	.85	.87	.89	.73	.91
	1962	.97	.95	1.0	1.0	.63	.99	.75	.78	.84	-.64	.64	.84
	1963	.93	.92	.98	.92	.95	.95	.96	.93	.82	-.69	.86	.90
	1964	.66	.75	.90	.76	.98	.95	.98	.76	.87	-.28	.47	.76
	1965	.71	.35	1.0	.93	.95	.96	.91	-.32	.74	-.63	.60	.74
	1966	.90	.45	1.0	.95	.97	.83	.99	.88	.73	-.95	.31	.82
	1967	.93	.96	1.0	.75	.85	.83	.98	.96	.77	.45	.83	.85
	1968	.99	.97	.98	.99	.96	1.0	.98	.85	.89	-.44	.76	.89
	1969	.99	.98	.98	.76	.99	.95	.98	.97	.73	.48	.90	.88
	Mean	.89	.81	.98	.90	.91	.93	.93	.78	.82	.59	.70	.84
C. Millstone and Raritan	1960	1.0	.64	.98	.92	.99	.96	.99	.77	.83	.96	.61	.88
	1961	1.0	.59	.88	.88	.99	.91	1.0	1.0	.87	.98	.37	.86
	1962	.99	.79	.99	.98	.61	.99	.82	.93	.84	.98	.91	.89
	1963	.98	.88	.99	.99	.95	.99	.99	.99	.83	.98	1.0	.96
	1964	.99	.80	.96	1.0	.95	.99	.92	1.0	.95	.95	.71	.93
	1965	.64	.23	.99	.85	.90	.87	.92	.30	.59	.96	.69	.72
	1966	.99	.70	.95	.85	.83	.92	.90	.90	.98	.93	.35	.85
	1967	.98	.98	1.0	.74	.82	.81	.90	.98	.90	.78	.91	.89
	1968	.99	.84	.99	.97	.79	.98	.95	.99	.98	.97	.96	.95
	1969	1.0	.97	.99	.87	.98	.89	.80	.67	.88	.97	.90	.90
	Mean	.96	.74	.97	.91	.88	.93	.92	.85	.87	.95	.74	.88

Summarizing, the factor structures of the Canal show a surprising similarity to those of the Millstone during the decade of the 1960s. The Canal also displays a structural congruence to the Raritan, but to a lesser degree. As might be expected for sub-basins of a larger basin, the Raritan and Millstone are structurally similar.

Thus, even though the decade of the 1960s included a record-breaking drought, the similarities among the factor structures over time and through space are greater than the differences.

2. Environmental Protection Agency (EPA)

The Water Quality Office of the U.S. Environmental Protection Agency (EPA) has collected an excellent set of data on the Raritan. The sampling program consisted of biweekly observations of 16 variables collected at 40 sites scattered throughout the basin in 1969 and 1970.

In contrast to the EWC data which represent a good sampling of water quality at three sites over time, the value of the EPA data lies in its spatial distribution of 40 sampling points. As shown in Figure 6, the coverage is particularly good in the tidal and central reaches of the Raritan and throughout the Millstone River.*

The average distance between sampling stations on the Raritan and Millstone is 2.7 miles. This represents the best coverage of any basin in the NYMR.

The mean DO profile for the Raritan Basin is shown in Figures 7 and 8. The following generalizations can be made:

a. There is a marked downstream deterioration in mean DO. The values drop noticeably from a plateau of 10 ppm or higher, upstream of the American Cyanamid Corp. plant, to a low of 5.5 ppm near Perth Amboy.

b. The Millstone DO profile is considerably lower than the Raritan at their confluence at river mile 23.6.

c. Except for the Millstone, almost all tributaries enter the main stream with higher average DO values.

d. The input of effluent from large sewage treatment plants strongly depresses the DO. Note the mean DO drop just below the American Cyanamid outfall at river mile 23.3 in Figure 7 and the Princeton outfall at river mile 15 in Figure 8.

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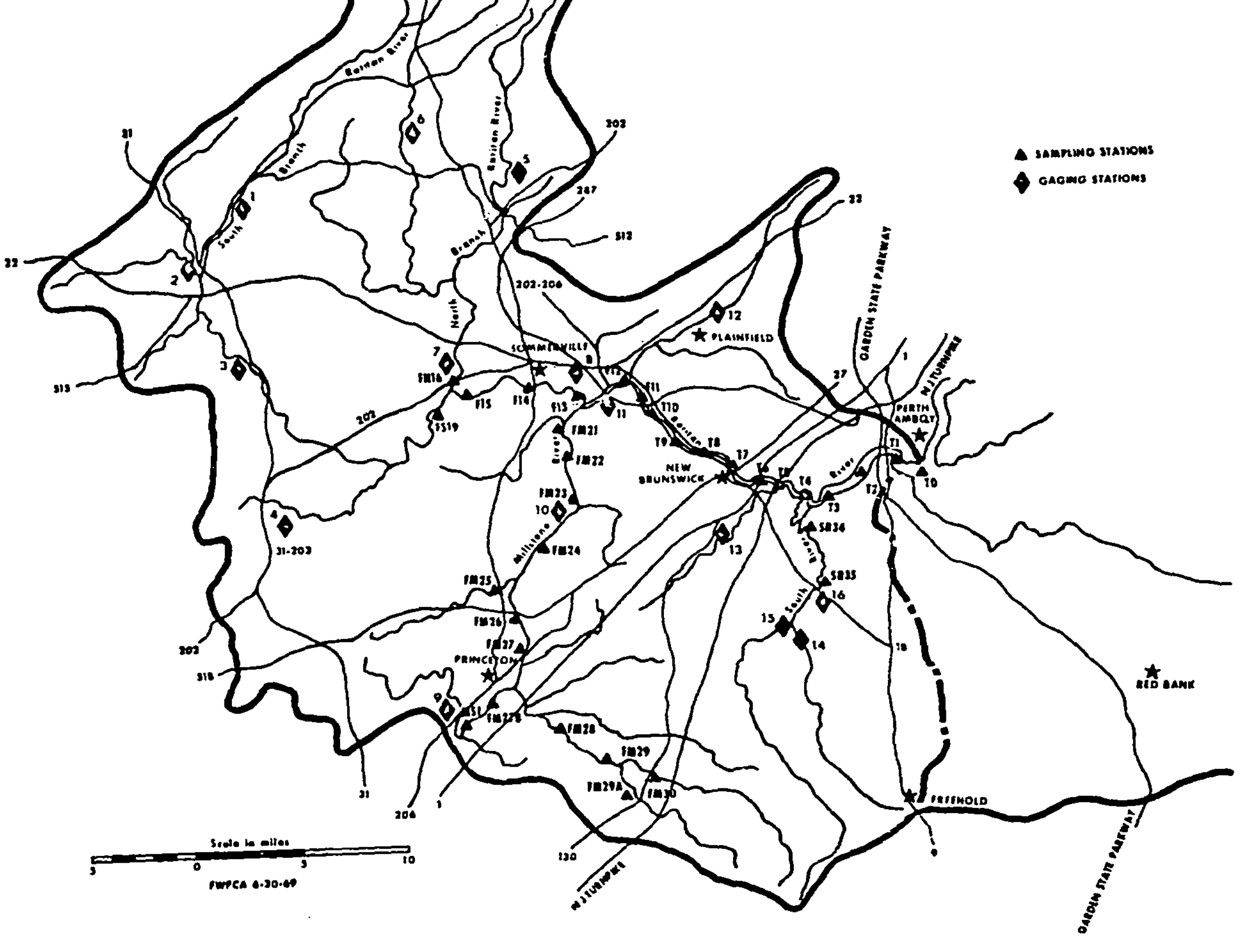
*The EPA data provided the base for the simulation model discussed in later chapters. The spacing of sampling sites is shown in Table 9.

Table 9. EPA Sampling Sites on the Raritan by Sub-Basin

Sub-Basin	No. of Sites	Average Distance Apart (miles)
Tidal Raritan	11	1.8
Upland Raritan	7	2.7
Millstone	9	3.7
Tributaries	11	-
Canal	2	5.3
	40	

FIGURE 6

RARITAN BASIN STUDY AREA
SAMPLING AND GAGING STATIONS



The impact of the average 25 mgd effluent from American Cyanamid is quite noticeable in Figure 9, which is a profile of mean fecal coliform concentrations in the Raritan Basin. Note the sharp rise from 1400 at river mile 23.7 to over 9,000 at river mile 19. The 25 mgd value for American Cyanamid also includes 4-5 mgd of domestic wastes from the Somerset-Raritan Valley Sewerage Authority (Whitman, Requardt and Associates, 1967). This arrangement between an industrial and a domestic sewage treatment plant is unique to the region. Essentially, the organic wastes from the domestic primary plant assist in the maintenance of a biological secondary plant for the industry.

Figure 9 also shows a sharp rise in fecal coliform levels just downstream of Albany Street Bridge, New Brunswick. Since there are no known sewer outfalls in the vicinity, the rise may be due to storm runoff coming from a heavily urbanized area and/or old leaky sanitary sewers in the city.

The seasonality of DO values and several data inconsistencies are revealed for two EPA sampling stations in the Raritan in Figure 10. The Central Railroad bridge site is at river mile 1.4 near Perth Amboy. It is the most downstream station in the EPA net, has the lowest mean DO of any of the 40 stations in the basin (5.5), and is the most subject to tidal influxes from Raritan Bay. The other site is on the North Branch of the Raritan at river mile 33.2 near Bridgewater Township. This station has one of the highest mean DO values in the basin (10.3), and represents an example of water quality in a largely rural watershed.

The following observations can be made regarding Figure 10:

a. The DO values at the Perth Amboy bridge site decrease sharply during the summer months to readings less than 4.0 ppm for eight occasions out of the 21 observations shown. Note that the state standards for this portion of the Raritan call for a minimum DO of 4.0 ppm at all times (State of New Jersey, 1971). Thus, the water quality at the bridge site failed to meet minimum requirements 38% of the time.

b. The North Branch station also experiences a decline during the summer, but in no case do values fall below 5.8. Almost all of the readings (90%) exceed 8.7, indicating DO levels close to saturation. The anomalous reading of 5.8 on April 23, 1969 could represent an unusual slug of pollutants coming down the river.

c. The value of 17.0 recorded on March 12, 1969 for the North Branch of the Raritan might have been caused by supersaturation or a sampling error. DO readings at normal sea-level pressure have lower and upper constraints of 0.0 and 14.7 ppm (Fair, Geyer, and Okun, 1968). Aquatic plant photosynthesis may liberate DO at times of supersaturation (Mackenthun, 1969), resulting in DO values exceeding the normal range.

FIGURE 7.

DISSOLVED OXYGEN PROFILE ON THE RARITAN RIVER, N.J.

(EPA DATA SET, ANNUAL MEANS)

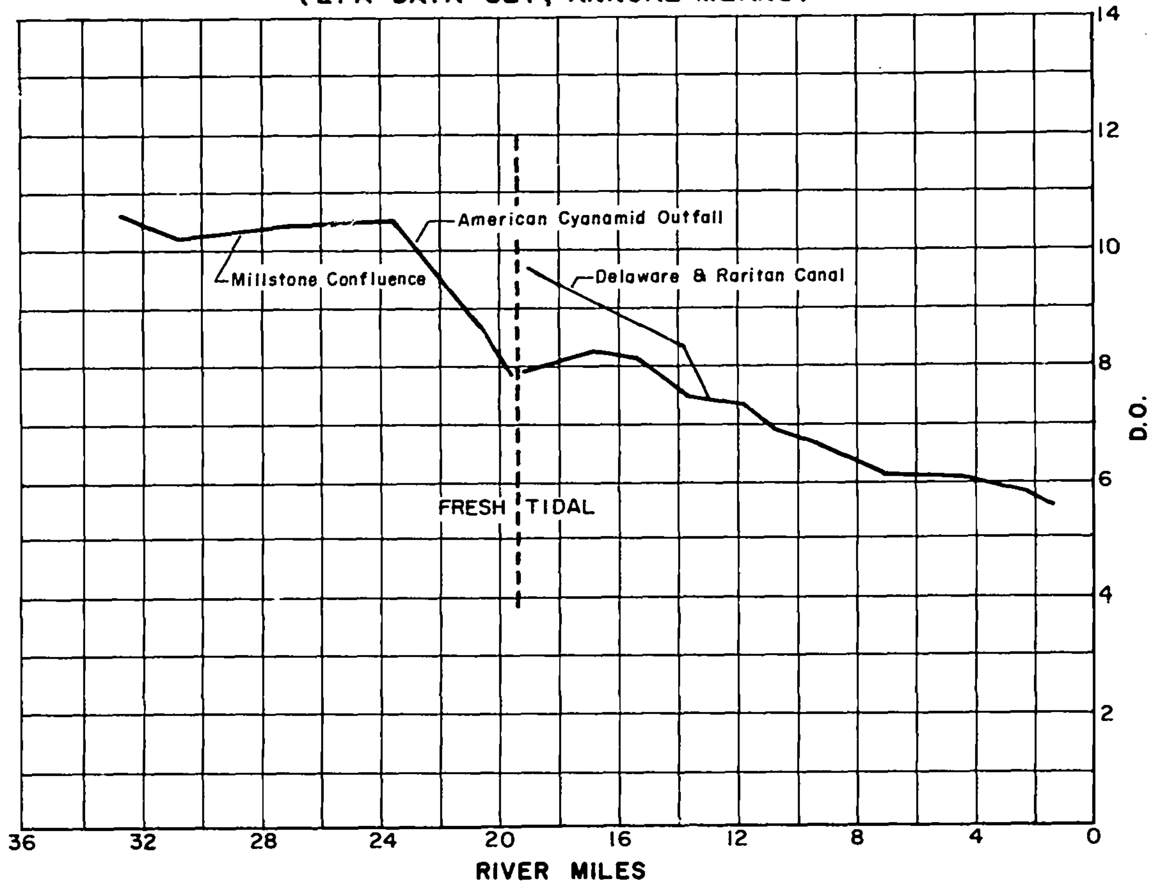


FIGURE 8.
DISSOLVED OXYGEN PROFILE ON THE MILLSTONE RIVER, N.J.
(EPA DATA SET – ANNUAL MEANS)

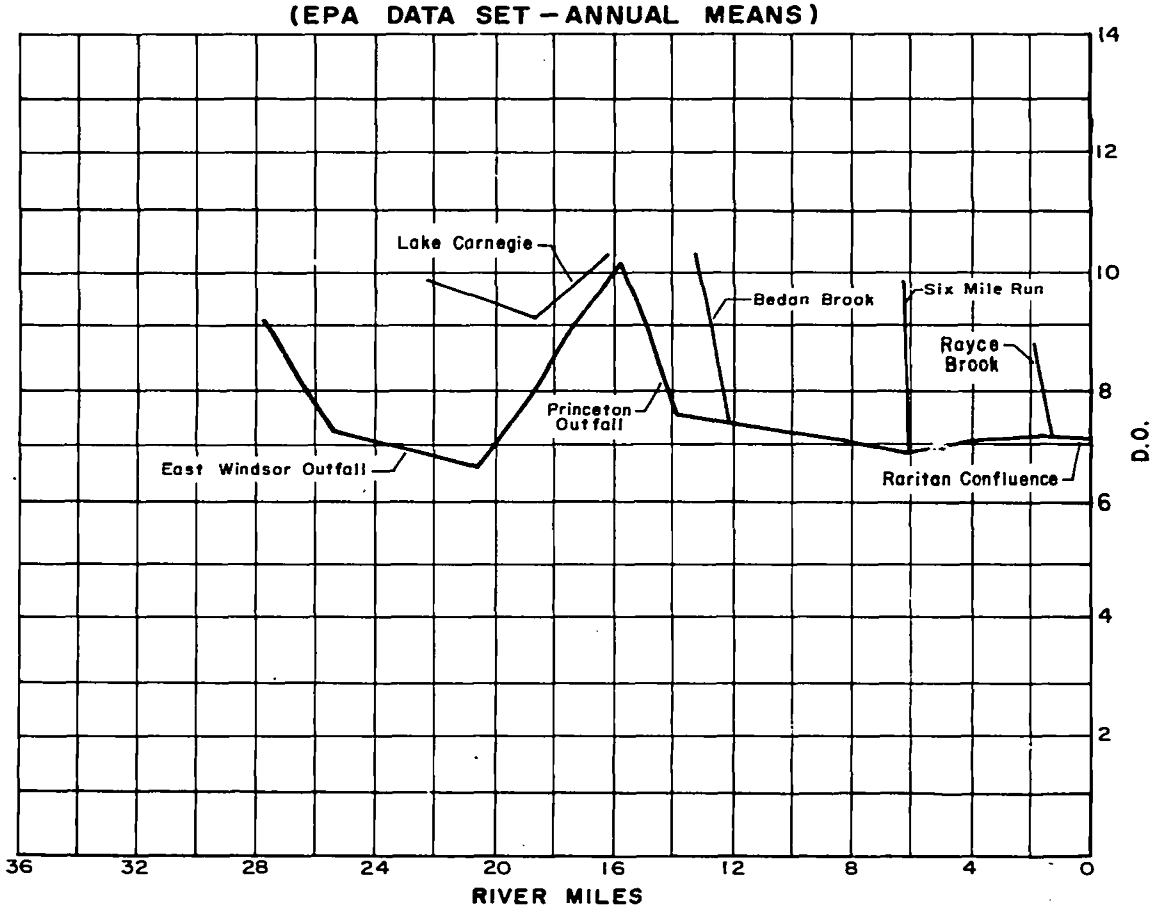


FIGURE 9.

MEAN FECAL COLIFORMS RARITAN RIVER, N.J.

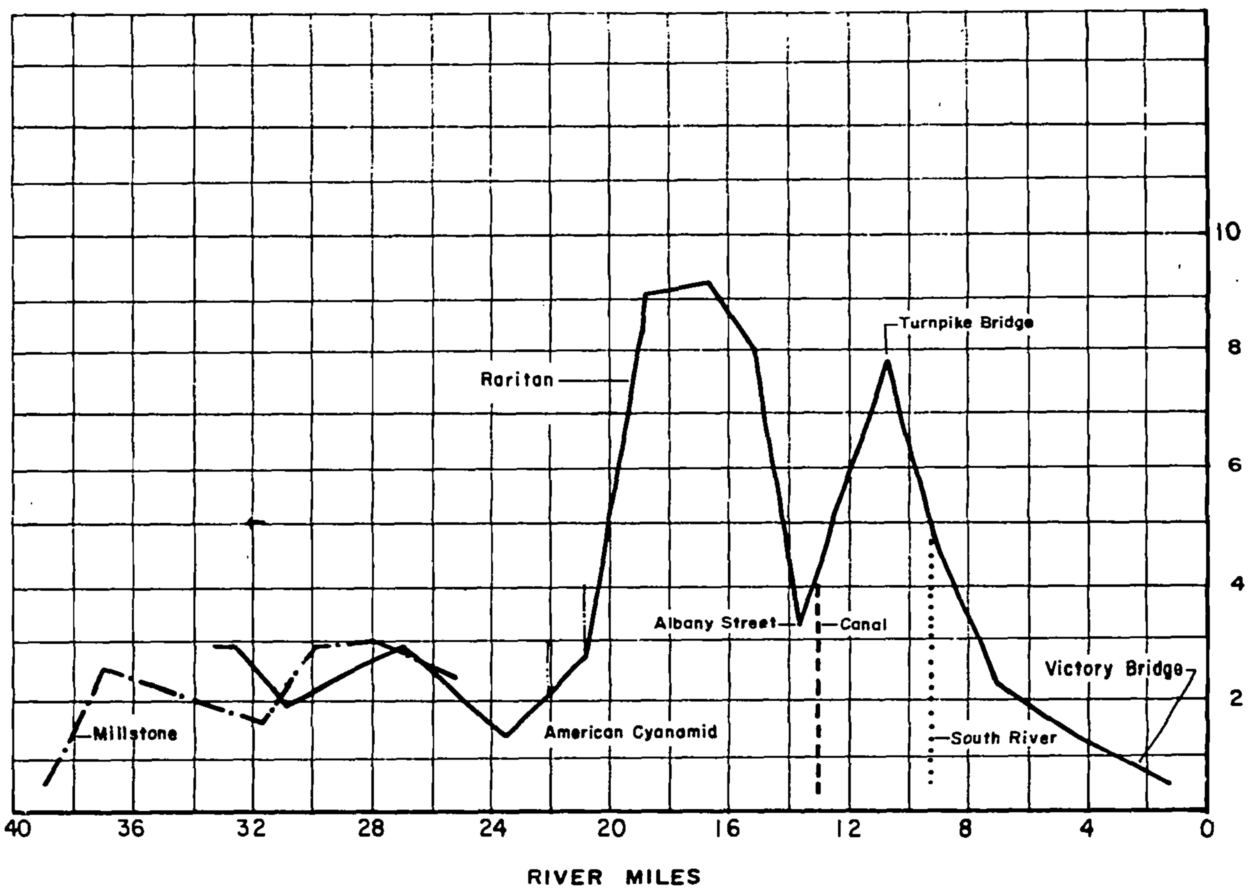
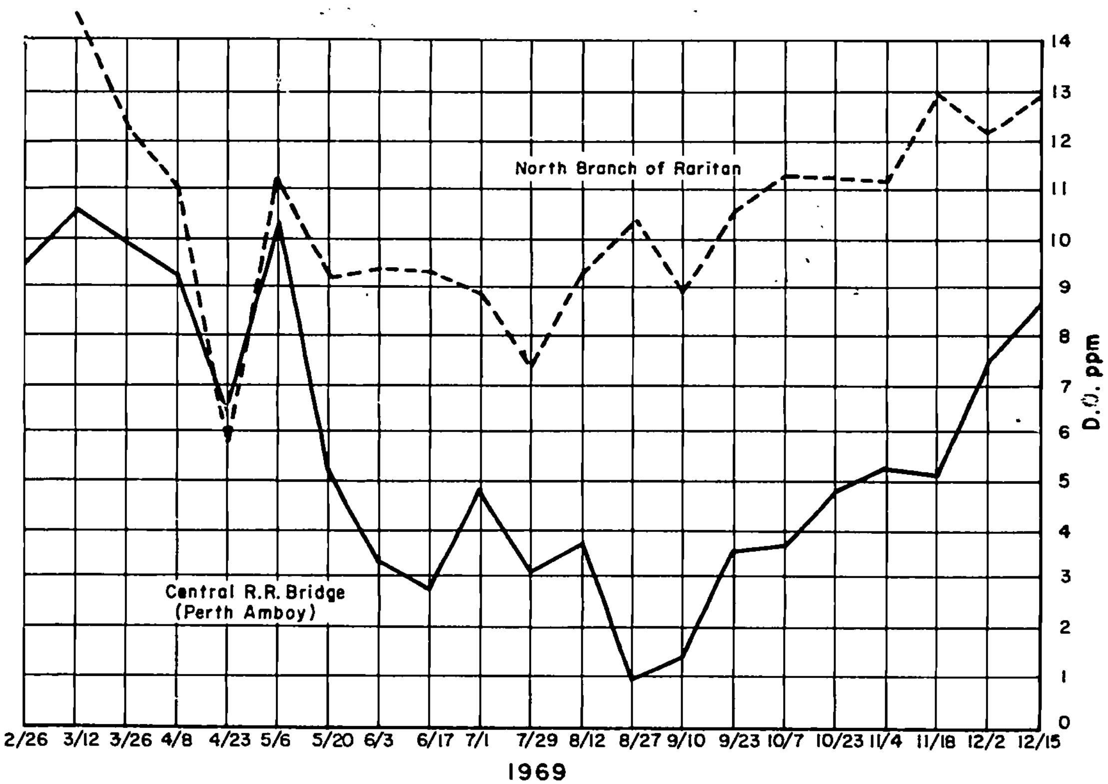


FIGURE 10.

D.O. VALUES FOR TWO-EPA STATIONS IN THE RARITAN, 1969



Factor Analysis

The water quality data collected at the 40 EPA sampling sites in the Raritan were subjected to factor analysis. Multiple correlation coefficients were used as estimates of communality and factors were rotated only if their eigenvalues exceeded unity.

Four different factor analysis runs were made, as follows:

a. All 40 stations individually, with as many variables as possible. This procedure resulted in 40 factor structures containing 16 or 17 variables, depending upon the availability of discharge readings.

b. All 40 stations individually, deleting those variables from Run 1 which had communalities lower than .50. The presumption is that the inclusion of variables with low communalities may introduce more noise than signal into the model.

c. 33 main stream stations grouped into seven categories based upon physical differences in the basin; all variables (16 or 17) were included.

d. Seven categories, deleting those variables from Run 3 which had communalities less than .50.

In the interests of brevity and also because of the general similarity of factor structures, only the results from Run (d) will be discussed.

Table 10 lists the significant factor structures for the seven groups. The first group consists of 11 stations on the tidal portion of the lower Raritan. The structure reveals an oxygen-status factor, a saturation factor and a third factor related to salts. Note that these stations regularly experience tidal incursions from Raritan Bay, resulting in a group mean chloride level of 3750 ppm (ocean water is about 19,300 ppm).

The two stations on the "South River" are also tidal. However, two factors are sufficient to explain 86% of the total variation. This cumulative explanation is the highest of the seven groups.

The three stations on the "Raritan below the Millstone confluence" show one large factor linking together saturation, ammonia, conductivity, chlorides and the coliforms. This reach of the river receives the effluent of American Cyanamid and Johns Manville Corporations.

The coliforms appear with high factor loadings in the "Raritan above the confluence" group. The group mean DO of the four stations is 10.4, the highest of any of the groups.

As discussed previously, the Canal water comes from the Delaware River above Trenton. Consequently, some differences in the factor structure may be expected. And, as shown in Table 10, organic nitrogen, phosphate and nitrate appear with high factor loadings, the only time this occurs in the basin. Coliform and fecal coliform also form another factor, but it is

Table 10. Rotated Factor Structures of Seven Hydrologic Groups on the Raritan River, New Jersey (EPA data set, 1969-1970)

Hydrologic Group	Factor	% Expl.	Air Temp.	Water Temp.	DO	BOD	Alk.	Turb.	SAT.	NH_3	Colif.	(colif) Fecal	Other Variables
	I	28	.87	.93	-.81								
Tidal	II	27				.61	-.63						*Cond. -.86 Chl. -.73
11 Stations	III	16							.94				
n=415	All	71											
South River	I	52					.88		-.76	.84			Cond. 92 Chl. .89
2 stations	II	34	.91	.96	-.80								
n=76	All	86											
Raritan below	I	34							-.86	.80	.67	.67	Cond. .63 Chl. .80
Confluence	II	18						-.84					Q -.85
3 stations	III	23	.93	.97	-.74								
n=112	All	75											
Raritan above	I	30						.80			.89	.95	
Confluence	II	31	.91	.97	-.89								
4 stations	III	18							.97				
n=153	All	79											
Canal	I	36				.64				.70	.94	.95	Org.N .87 PO_4 .93
2 stations	II	23	.92	.97	-.77								NO_3 -.65
n=71	III	24							-.70				Cond. .94 Chl. .90
	All	83											
Millstone	I	26	.88	.94	-.78								
9 stations	II	19						.68			.75	.87	
n=330	III	22			-.58	.53	.69		-.71	.70			
	All	67											
Carnegie Lake	I	25	.89	.98	-.47	.56							NO_3 -.58
2 stations	II	21						.77			.89	.95	
n=67	III	21			.83	.55			.91				pH .60
	All	67											

*Cond., conductivity; chl., chlorine.

believed that runoff and leaky sewers from the city of New Brunswick may account for the high loadings. Indeed, the mean coliform counts for one Canal station just below New Brunswick is very high.

The Millstone and Lake Carnegie groups reveal several similarities. For example, (a) the DO variable splits its association between two factors; (b) turbidity and coliforms together form a separate factor; and (c) the cumulative percentage of explanation is 67% for both groups. This is the lowest percentage of explanation of any of the seven groups. Since the Millstone flows into Lake Carnegie, some of the similarities may be expected.

In summary, the following observations can be made:

a. A temperature-DO factor appears in all groups, accounting for an average 35% of the cumulative explanation. It is usually, but not always, the first factor in importance.

b. All factor loadings for BOD are less than .65. When BOD does appear with a loading greater than .50, it is generally not with the temperature-DO factor.

c. Coliform and fecal coliform form another independent factor, usually including turbidity.

d. A third variable factor loads highly on conductivity and chlorides, or on saturation, or on all three variables.

e. Deleting variables with low communalities and then running a new factor analysis with a reduced set of variables raises the cumulative explanation about 10% and generally decreases the number of factors. Essentially the same conclusion was reached by Spiro (1971) in his factor analysis of the individual stations. Spiro found an average increase in explanation of 8% when variables with communalities less than .50 were removed and the analysis was repeated.

f. Intrabasin factor structure comparisons are difficult because of the varying number of variables for each group. Factor analysis options were an eigenvalue cutoff of 1.0 for rotation and a communality .50 or less for variable deletion. Consequently, the variables ranged from eight for the South River group to 13 for the Canal out of a possible total of 17. However, even though the groups were nonuniform in number of variables, several characteristic water-quality factors still emerged.

3. Passaic Valley Water Commission (PVWC)

If the strength of the EWC data lies in the temporal domain and the EPA data, in the spatial domain, then the PVWC data occupy an intermediate position. The EWC samples were conducted weekly for 10 years for three sites while the EPA set were biweekly at 40 sites for 18 months. the PVWC samples are monthly for 17 sites scattered throughout the basin, 11 of which have records going back to 1960 -- the beginning of our study period.

The Passaic basin is one of the largest basins in New Jersey. It was also voted one of the "ten dirtiest rivers in the U.S." Consequently, the PVWC, a large public potable water supply agency, is vitally concerned with the quality of its raw intake water. PVWC maintains at its own expense a network of 17 stations upstream of the Little Falls treatment plant. Conditions in the river are grim -- at times of low flow as much as 40% of the discharge is partially or poorly treated sewage coming from upstream plants. Railroad tank cars of chlorine gas are brought in regularly to the Little Falls filter plant in order to superchlorinate the raw river water prior to conventional treatment. Even the chief engineer of PVWC admits that his filter plant has been forced to become a tertiary sewage treatment plant for the entire upland basin (Inhoffer, personal interview) in the absence of effective pollution control measures.

The Passaic basin can be conveniently divided into three regions: (a) a forested, steeply sloping highland zone with numerous reservoirs and few people; (b) a low-lying intermediate zone with gentle slopes and numerous swamps; and (c) a heavily industrialized zone along the tidal reaches of the Passaic. The PVWC sampling sites are almost entirely in the intermediate zone.

Another division of the basin can be made based on water quality. If we schematically represent the upland Passaic as in Figure 11, then the northern division includes the Pequannock, Wanaque, and Ramapo Rivers, which merge near Pompton Plains to form the Pompton River. The Pequannock watershed includes five reservoirs with a storage capacity of 14.5 billion gallons. The Wanaque watershed contains two large reservoirs (Greenwood Lake and Wanaque Reservoir) with a combined storage capacity of 35.2 billion gallons. These watersheds have a low density of population and are mostly forested.

The southern division includes the Whippany and Rockaway Rivers which drain into the upper Passaic. The Rockaway watershed includes two reservoirs operated by Jersey City with a combined storage capacity of 10.9 billion gallons. However, the same watershed includes a large sewage treatment plant just below Boonton Reservoir which is notorious for its low efficiency. Since the Jersey City Reservoir did not have any release requirements from its watershed until quite recently, the flow in the Rockaway River below Boonton consisted almost entirely of poorly-treated sewage. Indeed, during the drought summers of 1962-66, the reservoir spill was a mere trickle compared to the sewage effluent. The figures are documented in Table 11. Note the secular rise in effluent from an already overloaded plant.

Other problems exist in the southern division. The Whippany Paper Board Company operates a large mill on the Whippany. The effluent is high in oxygen-demanding wastes. The mill has been a recurring problem to the

Table 11. The Average Amount of Sewage Effluent Released into the Rockaway River Below the Boonton Reservoir, Summer Months, 1960-69

Summer[a]	Gage Discharge[b]	Sewage[b]	Is Sewage Greater than Discharge?
1960	129.5	7.9	
1961	16.0	6.7	
1962	0.6	6.0	Yes
1963	4.7	7.0	"
1964	6.4	7.9	"
1965	0.5	9.0	"
1966	1.9	8.3	"
1967	96.1	11.3	
1968	92.8	12.8	
1969	77.4	12.3	
Mean	42.6	8.9[c]	

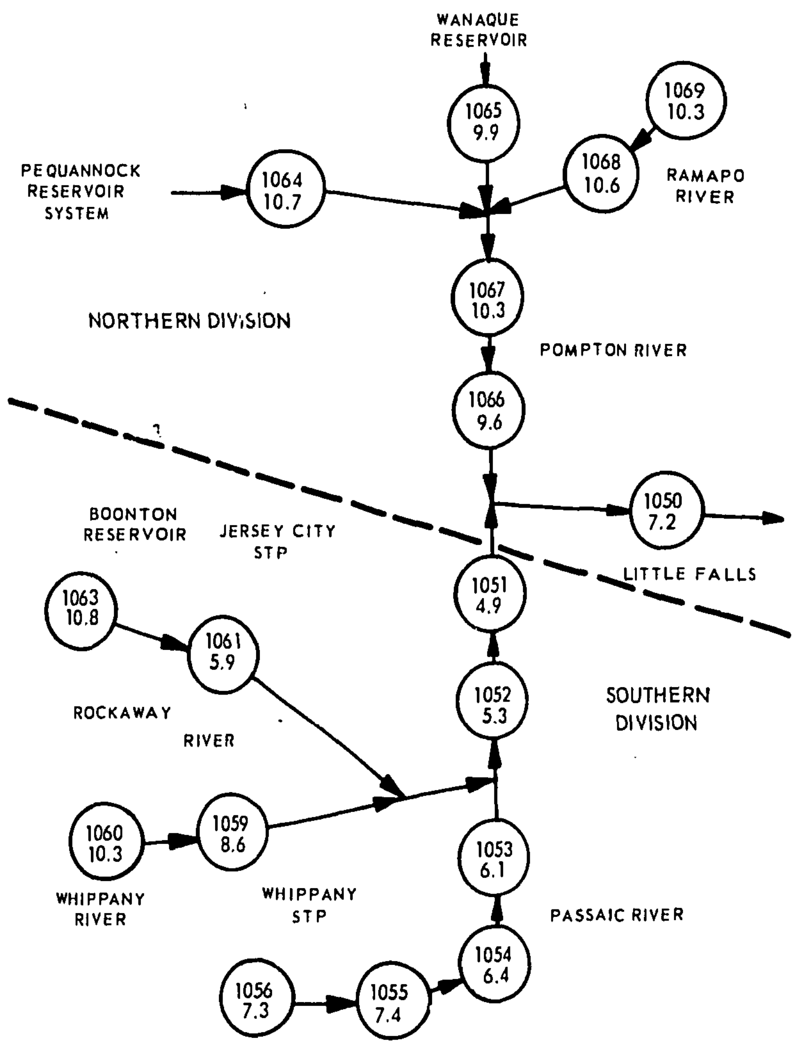
[a] June, July, August and September

[b] cfs

[c] equivalent to 5.75 mgd

FIGURE 11

SCHEMATIC MAP
of the
PASSAIC VALLEY WATER COMMISSION SAMPLING SITES



Note: Upper figure indicates Project Station I.D. number; lower figure indicates mean DO.

downstream PVWC, necessitating court injunctions to curtail mill operations (Roby, personal interview). In order to avoid legal challenges, the company has recycled a considerable portion of its effluent, thereby reducing the volume of waste discharged into the stream.

The upper Passaic flows sluggishly through poorly-drained, marshy areas upstream of the Pompton confluence. Slopes are very gentle; indeed, the average slope for the main stem of the upland Passaic is only 1.8 feet/mile (McCall and Lendo, 1970).

The effects of the aforementioned divisional differences are clearly evident in the mean values of selected water quality variables. Table 12 documents these differences for DO, BOD and color during the predrought (1960-62), drought (1963-66), and postdrought (1967-69) years. The southern division is consistently lower in DO and higher in BOD and color than the northern division.* The bottom two rows in Table 12 show that the southern division accounts for an average of 55% of the flow at Little Falls.

In conclusion, PVWC is highly dependent on the higher-quality water from the northern tributaries to dilute the poorer-quality water coming from the southern division. The agency is extremely sensitive to effluents being discharged into the watershed, as it occupies a vulnerable downstream position. Continued development of the basin without effective pollution abatement measures can only lead to increased difficulties for the PVWC and the possible loss of a major water supply for the region.

<u>Factor Analysis</u>

The usable portion of the PVWC data, consisting of 17 variables collected at 17 stations at semimonthly to monthly intervals, was grouped into three periods:

a. 1960-62 - predrought

b. 1963-66 - drought

c. 1967-69 - postdrought

The data were examined by factor analysis. The usual factors were extracted -- oxygen status, appearance, and dilution factors. The average statistical explanation for the decade was 72 percent. The details of the methodology and findings are presented in the Statistical Supplement (see Preface, p. i).

*For an interesting, documented report elaborating on the divisional differences and on water pollution problems in the Passaic basin in general, the reader is referred to a Princeton Seminar report entitled, Water Pollution in the Passaic River Basin, New Jersey: Analysis of Problems and Recommendations for Possible Solutions, Report Prepared by Students in the Student-Initiated Seminar: Technology and Society: Problems in the Human Environment, Spring 1970, Princeton University.

Table 12. Mean Values of Selected Water Quality Variables for the Major Divisions of the Passaic Basin

Division	Variable[c]	1960-62	1963-66	1967-69	Decade
Northern[a]	DO	10.2	10.1	10.3	10.2
Southern[b]	"	6.2	7.0	7.5	6.9
Northern	BOD	2.5	3.1	3.3	3.0
Southern	"	8.1	8.7	6.3	7.7
Northern	Color	25.3	27.2	27.8	26.8
Southern	"	59.0	60.4	71.1	63.5
Northern	Discharge	306	178	408	297
Southern	"	329	270	527	376

a comprises six stations on the Pompton, Ramapo, Wanaque, and Pequannock tributaries.

b comprises four stations on the Rockaway and Whippany tributaries and six stations on the upper Passaic.

c all values in ppm except for discharge in cfs.

4. Hackensack Water Company (HWC)

The Hackensack River Basin is one of the most regulated watersheds in the eastern United States. Its upland portion, as measured by the USGS gage at New Milford 22 miles upstream from Newark Bay, covers 113 square miles. Within this relatively small area on the sandstones and shales of the Triassic Lowland of Bergen County, New Jersey, and Rockland County, New York, are four reservoirs which develop the basin's full surface water capability. Thus, the basin may be viewed as a series of reservoirs connected by gently sloping streams.

The main-stem reservoirs are DeForest Lake in Rockland County and Oradell Reservoir in Bergen County, with storage capacities of 4.1 and 2.85 billion gallons, respectively. The oldest and smallest reservoir is Woodcliff Lake, built in 1905 on Pascack Brook, a major tributary of the Hackensack and having a storage capacity of 0.84 billion gallons. Lake Tappan, the fourth reservoir, was built in 1966 in response to the rising demand for water; it straddles the state line and has a storage capacity of 3.4 billion gallons.

The Hackensack Basin differs from both the Passaic and Raritan basins. Almost all its sewage treatment plants discharge their effluent either into short tributaries leading to the Hudson (such as Sparkill Creek) or into the tidal portion of the Hackensack (such as the Bergen County Sewerage Authority plant at Little Ferry). Troublesome problems do exist in the basin, as evidenced by occasional effluent loadings from a large pharmaceutical firm in Rockland County (Pallo, personal interview) and by whole communities still relying on septic systems (such as Closter).*

Secondly, most of the Hackensack Basin is hydrologically managed by one agency -- the Hackensack Water Company (HWC). Founded in 1869 (Leiby, 1969) HWC is the second largest private purveyor of potable water in New Jersey. HWC maintains its own stream-sampling network of 14 stations in both Bergen and Rockland Counties. Our data bank consists of eight major stations sampling 6-15 variables at approximately weekly intervals for the 1960-69 period. Our statistical analysis was based on over 38,000 bits of information.

Certain trends in water quality in the basin can be delineated by examining one station in some detail. The Rivervale, New Jersey station is located 31 miles upstream from Newark Bay. The sampling site was flooded out by the new Lake Tappan reservoir on September 15, 1966 and was moved to the downstream portion of the reservoir. The drainage area is about 49 square miles.

As shown in Figure 12, the annual DO means range from a low of 7.5 in 1965 to a high of 10.2 in 1968, averaging 8.9 for the decade. The mid-decade slump is associated with the previously-discussed drought. DO levels are generally satisfactory, at least on an average annual basis.

*Closter is in the process of constructing a sewerage system whereby the effluent will be treated at the large Little Ferry plant. Considering a density of over 2,400 persons/square mile, it is surprising that Closter remained on septic systems for so long.

A pronounced secular trend is noted in Figure 12 for annual chloride means. Not only is the average concentration of salt ions rising, so are the standard deviation values, particularly during 1969. The increasing use of rock salt as a de-icing agent during the decade is the probable cause.*

Figure 12 shows another secular increase in the nitrate (NO_3) variable. Both the means and variances double in value after 1967. The explanation for the sharp increase presumably lies in the enlarging and additional construction in Tappan Lake Reservoir in the latter part of the decade.

It is worth mentioning again at this time that even good sets of data such as the HWC's have irregularities. For example, although the sampling frequency is purportedly weekly, the number of observations/year at the Rivervale site varied from 41 in 1969 to 56 in 1962. Other stations have even spottier records, such as the West Nyack, New York site on the Hackensack River below DeForest Lake, which was sampled only eight times in 1960. For the remainder of the decade, the frequency was essentially biweekly.

Serious questions of reliability are raised with certain station data sets. For example, 24 separate instances were recorded at the Woodcliff Lake site during 1960-69 wherein DO values exceeded 20 and even 30 ppm. These instances were distributed throughout all seasons and all years. The inflated values may possibly be associated with strong turbulence resulting from high flows at the spillway pipe (Schwartz, personal communication). Whatever the reason, objections can be raised as to sampling location.

Factor Analyis

Eight upland sampling sites in the Hackensack Basin were factor analyzed. Again, typical structures were found consisting of temperature-DO, dilution (discharge, alkalinity, pH, chlorides), and appearance. The HWC data are generally similar to the other sets, but the effects of impoundments and the absence of on-stream major sewage outfalls are noticeable. The details of our findings are given in the Statistical Supplement (see Preface).

5. New Jersey Sewage Treatment Plants

There are nearly 400 separate sewage treatment plants in northeastern New Jersey,**according to the most recent compilation by the State of New Jersey (New Jersey, Department of Health, 1968). The design capacity of

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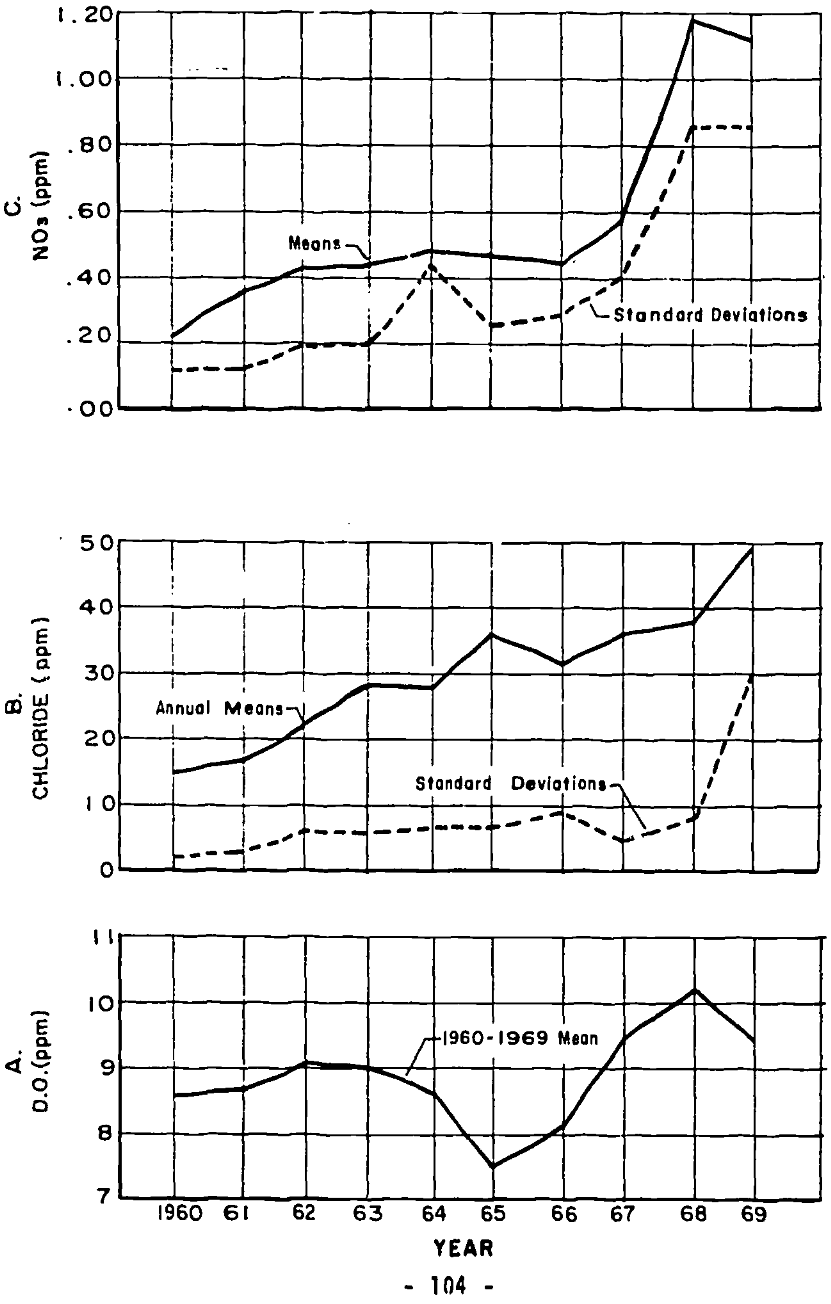
*This presumption is substantiated by the findings of Broecker, Schwartz, Sloan, and Ancona in a 1971 Lamont-Doherty Geological Observatory Contribution No. 1681 entitled, Road Salt As An Urban Tracer. Essentially, Broecker *et al.* associated the rise in chloride levels in Woodcliff Lake and Oradell Reservoir from a background level of 10 ppm in 1930 to 50 ppm in 1970 to large increases in rock salt usage by state and county road departments. For example, road salt applications in Bergen County rose from 3,700 tons in 1963-64 to 14,800 tons in 1969-70.

**includes Bergen, Passaic, Essex, Hudson, Morris, Union, Middlesex, Somerset, Monmouth Counties and the Millstone drainage portion of Mercer County.

FIGURE 12.

DISSOLVED OXYGEN CHLORIDE, NITRATE
OF WEST HACKENSACK RIVER AT RIVERVALE, N.J.
1960-1969



the plants ranges from many small package plants of less than 0.001 mgd to the 200 mgd plant of the Passaic Valley Sewerage Commission (PVSC), the largest one in New Jersey.* The cumulative sewerage capacity exceeds 760 mgd.

The frequency distribution of sewage treatment plants using logarithmic class limits is shown in Table 13. There is a pronounced decrease in the number of plants as capacity increases. If we exclude from Table 13 those plants with capacities less than 0.1 mgd, we still have 175 plants scattered throughout the nine and one-half counties. Note the effect of large regional plants -- the capacity of the 13 largest plants amounts to 547 mgd, or 72% of the total. Indeed, the PVSC plant alone accounts for 26% of the total capacity.

Northeastern New Jersey can be divided into nine regions based on receiving waters -- six tidal zones and three upland sewersheds. As indicated in Table 14, 80% of the cumulative capacity is discharged into tidal waters having only 30% of the total number of plants. This observation is to be expected, inasmuch as sewer development spread out from core areas located on or near tidal watercourses.

It is interesting to speculate what would happen if state-supported plans for regionalization accelerate during the next several decades. For one thing, the total number of plants would decrease, since small package plants would be either abandoned or converted into pumping stations. This process has already begun in a number of areas (Bergen and Middlesex Counties). Secondly, there has been an upstream expansion of sewersheds served by a large regional plant located on tidal waters.** This expansion of treatment capability has the salutary effect of facilitating suburban development while presumably maintaining water quality, but it adversely affects the flow regime of upland rivers.

If we assume that the 138 plants on the Passaic and the 137 plants on the Raritan-Millstone were operating at capacity (see Table 14), then the effluent could account for 18% and 22% of the mean monthly summer discharge, respectively.*** Diversion of this effluent by piping it directly to the sea eliminates one portion of the hydrologic cycle and may seriously deplete streamflow during prolonged dry spells. Can the region afford once-through water? In the light of interesting results in the renovation of waste waters by using upland soils (Parizek, 1967) as a living filter, perhaps the abandonment of dispersed small plants should be questioned.

The average annual flows of three major regional sewage plants in New Jersey are indicated in Fig. 13. Note that the ordinate is scaled logarithmically so as to show rates of increase or decrease.

*In order to ensure some degree of uniformity, the size of plants will be indicated by the design capacity. Exceptions to this rule will be specifically denoted. Selected large regional plants will also be treated separately.

**Several specific instances will be documented later.

***These values were computed by averaging the long-term means of July, August, and September as reported by Laskowski (1970) for the respective basins.

Table 13. Frequency Distribution of Northeastern New Jersey Sewage Treatment Plants by Size, 1968

Design Capacity (mgd)	Number of Plants	Cumulative Capacity	Percentage of Total Capacity
0.001 - 0.01	56	0.3	-[a]
0.01 - 0.1	161	5.2	-[a]
0.1 - 1.0	99	41.0	5
1.0 - 10.0	62	168.1	22
10.0 - 100.0	12	346.8	46
greater than 100	1	200.0	26
TOTAL	391	761.4	99

Source: (New Jersey, Department of Health, 1968).

[a] less than 1%.

Table 14. Frequency Distribution of Northeastern New Jersey Sewage Treatment Plants Receiving Waters, 1968

Receiving Waters	Number of Plants	Percentage of Total	Cumulative Capacity (mgd)	Percentage of Total
Hudson River	10	3	285	37
Newark Bay	4[a]	1	60	8
Arthur Kill	12	3	85	11
Raritan Bay	31	8	63	8
Atlantic Ocean	38[b]	10	58	8
Hackensack River	21	5	62	8
Subtotal Tidal	116	30	613	80
Passaic River	138	35	63	8
Raritan River	94	24	72	9
Millstone River	43	11	13	2
TOTAL	391	100	761	99

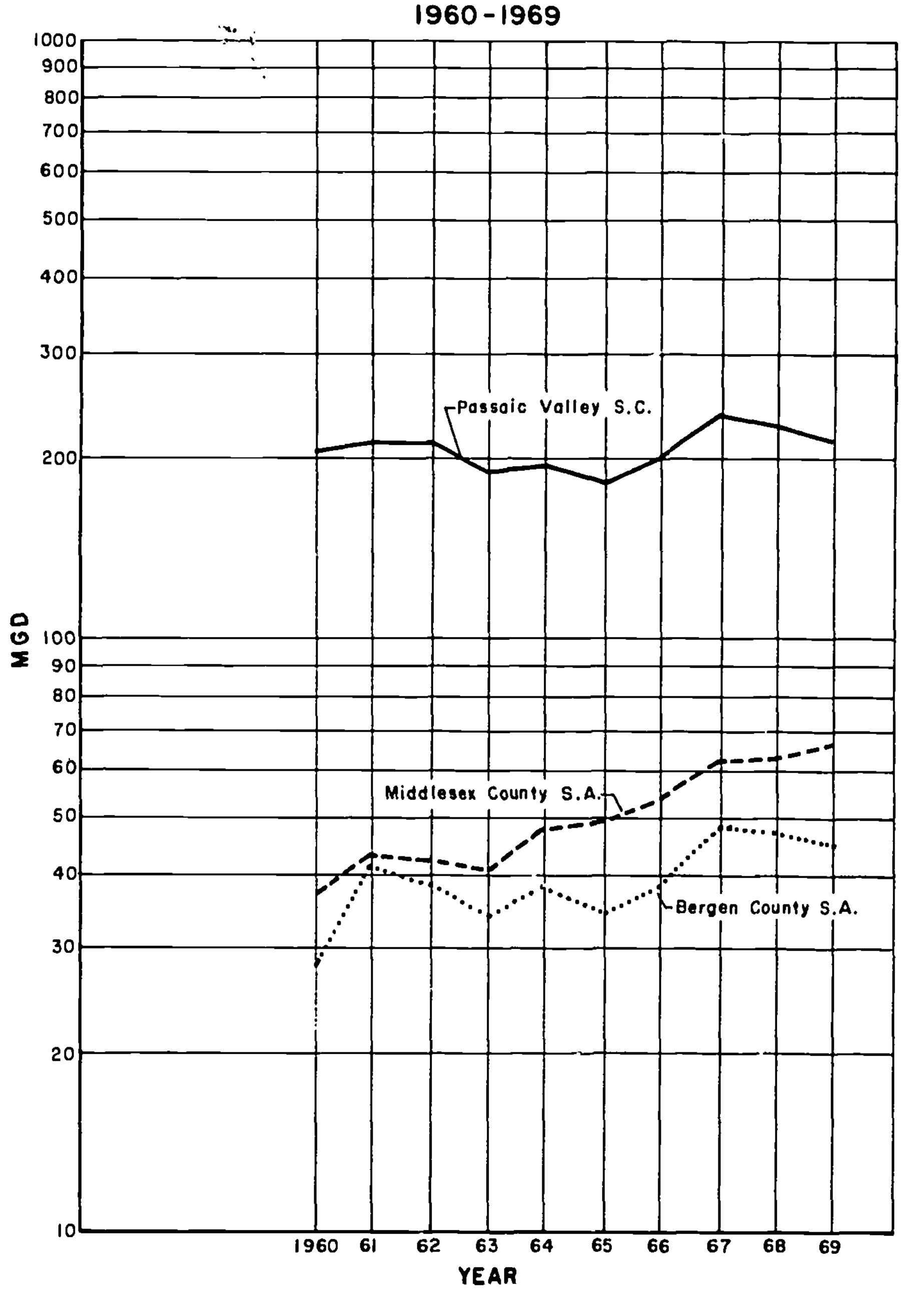
Source: (New Jersey, Department of Health, 1968).

[a] includes Kill van Kull

[b] includes Sandy Hook Bay

FIGURE 13.

AVERAGE ANNUAL FLOWS OF SELECTED NEW JERSEY REGIONAL SEWERAGE TREATMENT PLANTS 1960-1969



The largest treatment plant in New Jersey is located in Newark and is operated by the Passaic Valley Sewerage Commission (PVSC). Constructed in 1923, it is capable of only primary treatment, and somewhat poorly at that. The average annual effluent of over 205 mgd is discharged into Upper New York Bay at Robbins Reef, several miles south of the Statue of Liberty.

The PVSC sewershed consists of 28 municipalities and over 1,000 industries, of which 67 are of major size. These large industries have a total contributory flow of 57 mgd. Although this represents only about 27% of the average total tributary flow, it is estimated that the population equivalent is about one million persons, accounting for half the flow strength in terms of population equivalent (Manganaro, Martin and Lincoln Engineers, 1968). The total contributory population in 1960 was 1,117,000.

PVSC has been embroiled in controversy with the State for some years. The agency contends that it is somewhat autonomous of the State because of previous legislation, a view that has been challenged by the State. It is estimated that a new secondary treatment plant at the site would cost in excess of $300 million (Ready, personal interview). Financial difficulties are anticipated, since a number of the older core cities (such as Newark) are close to bankruptcy.

The impact of the PVSC effluent on New York Bay is considerable. Since a substantial portion of the PVSC flow consists of industrial wastes with high BOD loadings, the plant output actually exceeds the total loadings in the harbor caused by raw sewage being discharged directly from the west side of Manhattan. In a study prepared for the Interstate Sanitation Commission, the engineering firm of Quirk, Lawler, and Matusky (1967) estimated the total PVSC load discharged to Upper New York Bay to be 650,000 pounds of BOD/day, as compared to 363,000 pounds for New York City.

One of the most rapidly expanding sewage treatment plants in New Jersey is that of the Middlesex County Sewerage Authority (MCSA). Originally formed in 1950, the MCSA began operations in 1958. Average annual flow has more than doubled from 31 mgd in 1959 to 68 mgd in 1970 (MCSA Annual Report, 1970). The rapid growth rate is shown in Figure 13 for flow and in participants as follows:

Year	Municipal Participants	Industrial Participants	Total Number
1959	12	7	19
1970	18	9*	27

The outfall from the primary plant is located several miles offshore in Raritan Bay. The effluent leaves the plant with an average of 15% BOD

*Note that although the number of industrial participants is only half that of the municipal, the industrial flows constitute half that of the municipal, the industrial flows constitute half of the total flow in mgd and even more in terms of organic loadings.

removal. This situation will be improved by the mid-1970s when an $80 million secondary treatment plant including the UNOX or pure oxygen process is completed. Design capacity will increase to 120 mgd.

Although originally incorporated to serve most of Middlesex County, the Authority has included participants from Union and Somerset Counties. Continued growth can be expected, as upstream communities are pressured to join regional plants. Already, the consulting engineers for South Brunswick Township have recommended that half and possibly all of the township join the MCSA operation, even if it forecloses the possible use of the proposed Princeton regional plant on the Millstone (Bohren, Bogart and Van Cleef, 1971).

Another example of a rapidly-growing regional plant in suburbia is provided by the Bergen County Sewerage Authority (BCSA). As shown in Figure 13, the plant has grown from 28 mgd in 1960 to 45 mgd in 1969. The growth in participants in the Authority is briefly indicated as follows:

Year	Number of Participants	Estimated Population Served
1951	13	-
1969	31	460,000
1970s (est.)	43	650,000

The BCSA plant is located on the tidal portion of the Hackensack River at Little Ferry, downstream of Oradell Reservoir. Effluent leaves the plant with approximately 90% of the BOD and suspended solids removed (BCSA Annual Report, 1969).

Several primary plants have been abandoned in the county as the effective sewershed has expanded upstream. However, several municipalities with low population densities near the state line have opted not to join the Authority.

Recognizing that the existence of sewerage facilities increases water consumption, it is reasonable to assume that some communication would exist between water-supply and sewerage agency managers. Surprisingly, one finds minimum coordination between the agencies, even though a strong hydrologic system linkage exists. BCSA and HWC operate somewhat independently, are responsible to different directors and appear to function within narrow jurisdictional limits (Zablatzky, personal interview).

As previously mentioned, the sewer data do not lend themselves to any degree of sophisticated statistical analysis. Although many variables are listed on the forms, only a few are actually reported. Also, the availability of only two years of record for almost all plants rules out any observations of secular trends. The only exceptions to this are several of the large regional plants already discussed.

From the records of the Department of Health the sewerage system has expanded during 1960-1970. (New Jersey, Department of Health, 1963). The total number of plants in 1963 was 322 with a cumulative capacity of 733 mgd. The number rose to 391 by 1968 with a capacity of 761 mgd. Given the reliability of the data-collecting agencies, it is not certain whether this reflects a real increase or merely better reporting. Assuming that the first instance is correct, Table 15 documents the changes for each receiving watercourse zone.

The number of plants increased 23% and 31% for the tidal and upland zones, respectively. Certain zones had large percentage increases, such as the Raritan with 81%. The upland Passaic has the largest number of plants, but the numbers remained the same. However, most of the effluent (80%, Table 14) is discharged into tidal watercourses.

C. Connecticut

The information collected and analyzed for Fairfield County, Connecticut, may be aggregated into the following sets and subsets:

1. Housatonic River
    a. river at Shelton, Conn.
    b. well field along river at Shelton, Conn.
    c. river at Stevenson, Conn.
2. Saugatuck River
    a. river at Redding, Conn.
    b. Saugatuck Watershed
    c. Saugatuck Reservoir
3. Mianus River
4. Sewage Treatment Plants

Deficiencies of parameter selection, congruence, time and place of sampling made it impossible to perform a systemic analysis on the Connecticut data. For the most part, the data are suitable for routine reviews of isolated samples. Parameter means, standard deviations, factor structures and communalities were computed where appropriate. The results, revealing no striking trends, generally resembled the patterning of the New Jersey data, but without the hydrologic connectivities of the latter. On the whole, the Connecticut parameters showed a higher degree of behavioral independence and the factor analytic models provided a smaller explanation of the variance. This was probably due to the poorer structure of the raw data as well as the highly-regulated flow of the Housatonic River.

A more complete discussion of the Connecticut data is given in the Statistical Supplement (see Preface).

Table 15. Frequency Distribution of the Number of Northeastern New Jersey Sewage Treatment Plants by Receiving Waters, 1963 and 1968

Receiving Waters	Number of Plants 1963	1968	Percentage Increase or Decrease	
Hudson River	6	10	+67	
Newark Bay[a]	11	4	-64	
Arthur Kill	12	12	-	
Raritan Bay	24	31	+29	
Atlantic Ocean[b]	29	38	+32	
Hackensack River	12	21	+75	
Subtotal Tidal	94	116	+23	
Passaic River	138	138	-	
Raritan River	52	94	+81	+31
Millstone River	38	43	+13	
TOTAL	322	391	+26	

[a] includes Kill van Kull

[b] includes Sandy Hook Bay

D. <u>Westchester County, New York</u>

The hydrologic data collected and screened for the water bodies of Westchester County may be divided into the following groups and subgroups:

1. Waterways discharging into the Hudson River
    a. Peekskill Hollow Brook
    b. Indian Brook
    c. Pocantico Reservoir
    d. Tarrytown Lake
    e. Saw Mill River
2. Waterways discharging into Long Island Sound
    a. Sheldrake Lake
3. Croton Division of the Water Supply System of the City of New York
    a. Croton Reservoir
    b. Hallock's Mill Brook, no. 1
    c. Hallock's Mill Brook, no. 2
    d. Sodom Reservoir
    e. Croton River, Brewster
    f. Croton River, Croton Falls
4. Hudson River
    a. Chelsea

Much of the data collected in Westchester County are poor and suitable only for the computation of simple averages because the record contains few parameters, inconstant values, missing observations and includes short time periods. Record deficiencies also show station-to-station inconsistencies. Where comparable, the patterns of variable associations were familiar to the ones observed previously in New Jersey and Connecticut.

The data available for Westchester County were disappointing. Because of deficiencies, they did not warrant any more sophisticated analysis than simple descriptions in most instances. Given this data quality, it is not possible to prepare reliable, valid generalizations. Because the county is experiencing the pressures of urbanization and is an important producer of water for both its own use and export to New York City, local agencies are aware of the relation between waste water and potable water supplies.

Detailed reviews of its water sources and water disposal capacities have been completed recently (Comprehensive Sewerage Study, 1968; Comprehensive Public Water Supply Study, 1967).

In these studies, efforts were made to predict future volume demands for potable water sources and waste water facilities. In addition, waste water quality was expressed in units of suspended solids and BOD. Given these concerns and the need to anticipate the future, it is distressing that better records are not maintained for the assessment of the state of the water system.

In general, our findings of a slowly deteriorating water system in Westchester County agree with those of other reports.* The evidence is not decisive, however, for all areas. It would have been desirable if a common set of data had been available to permit detection of systems that were not deteriorating, if such existed. Their behavior could provide guidelines for management policy. Their absence, on the other hand, would indicate alternative options -- rising effluent treatment independent of, or concurrent with more intensive influent treatment; land zoning for water protection; or the abandonment of intraregional water production. Regrettably, the available data do not permit the exploration of these options.

A detailed review of our findings for Westchester County is given in the Statistical Supplement (see Preface).

*These reports do not describe in detail the data bases from which their conclusions are derived (Bureau of Water Supply, 1969; Comprehensive Public Water Supply Study, 1967; Report on Comprehensive Sewerage Study, 1968).

CHAPTER III

SCREENING OF THE HYDROLOGIC DATA:
LONG ISLAND GROUNDWATER

The potable water supply for the communities on Long Island is obtained from upstate surface water sources and local aquifers. The upstate sources are part of the New York City system that furnishes the needs for Brooklyn and most of the requirements for Queens.* A small share of the water needs of Queens is obtained from local wells operated by the Jamaica Water Company and the Woodhaven Water Company.

Lying to the east of Queens and occupying most of Long Island are Nassau and Suffolk counties. These rapidly urbanizing counties are dependent entirely on local aquifers to satisfy their expanding water demands. The groundwater information on the wells in Queens and the wells in Nassau County were treated as separate data sets.

1. Queens County, New York City, Long Island

Data collected on the producing wells of the Jamaica Water Company (JWC) in Queens County, Long Island, adjacent to Nassau County, were aggregated into two groups: 1960-1964 and 1965-1968. Means and standard deviations were computed for 14 variables. The results are given in Table 16.

Insofar as this short time series can be regarded as indicative of a trend, water quality appears to have deteriorated for many parameters. All the nitrogen variables -- NH_3, total N, NO_2 and NO_3 -- showed increases. The decline in quality is caused by the excess of the pumpage rate over the natural replenishment rate.

2. Groundwater, Nassau County, Long Island, New York

Information on the qualities of the 390 wells of Nassau County provided by the Bureau of Water Resources was ordered into separate files by parameters and aquifers. The aquifers are the upper Glacial, the Magothy and the Lloyd. The structural relations of the hydrogeologic units are shown in Figure 1.

Groundwater on Long Island is of much greater significance than surface water in the natural hydrologic cycle and as a potable resource. It has been studied intensively by numerous investigators (Cohen, Franke, and Foxworthy, 1968). About 90 percent of stream flow is sustained by groundwater inflow. For Nassau and Suffolk counties, groundwater furnishes the entire potable water supply. The recharge area is local, by infiltration from the overlying land surface. At present, aquifer inflow is dependent on natural infiltration, flows from cesspools and septic tanks, recharge basins to accommodate storm runoff and waste water, injection wells, and leakage. Groundwater discharge consists of natural outflows(such as discharges to streams, subsurface outflows to the ocean, evapotranspiration and springflow), and pumpage.

Under natural conditions the water budget was in equilibrium. Urbanization has caused serious interventions that have upset this balance. Gross

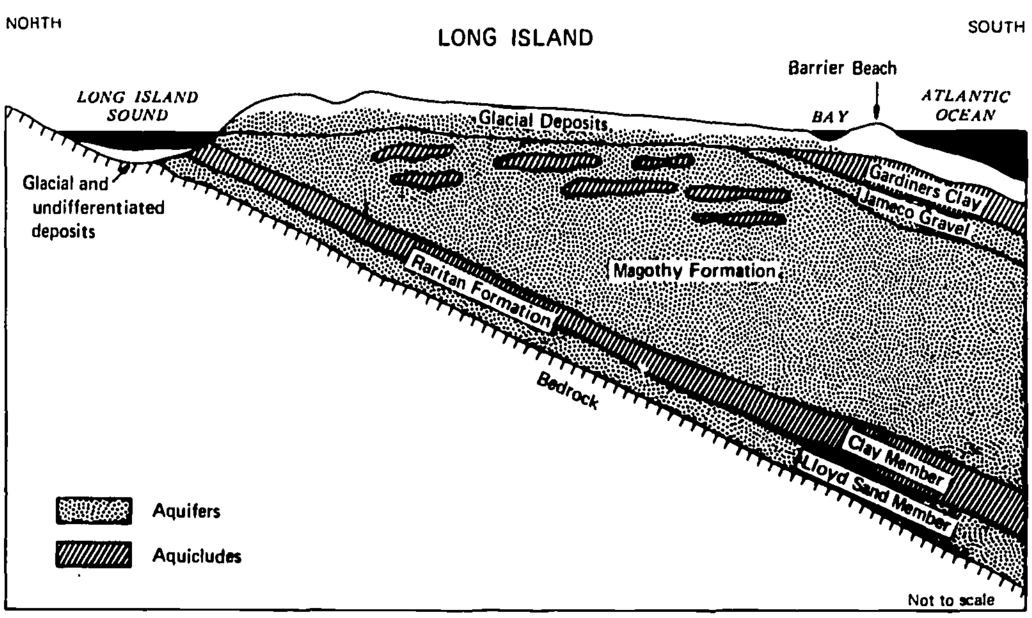
*Brooklyn and Queens are boroughs of New York City located at the western end of the Island; Queens lies east of Brooklyn.

Table 1. Groundwater Quality, Queens County, New York City, Long Island Means and Standard Deviations, 1960-1964 and 1965-1968 (JWC data)

	1960-1964, n = 196		1965-1968, n = 170	
Parameter	Mean	Stand Dev.	Mean	Stand. Dev.
Turbidity	2.0	3.3	2.0	2.6
Color	6.3	7.9	7.4	9.8
NH_3	.035	.043	.072	.055
Total N	.404	.301	.651	.575
NO_2	.002	.007	.003	.006
NO_3	4.2	3.3	6.47	3.8
Spec. Cond.	289	159	307	174
Total Solids	206	119	209	128
Chlorides	15.5	9.3	16.5	9.5
Hardness	121.9	85.9	119.1	88.6
Alkalinity	61.7	53.5	54.0	54.1
pH	6.6	.57	6.6	.54
Fe	.300	.573	.226	.728
O_2con	.741	.725	.733	.260

FIGURE I.

GENERAL RELATIONSHIPS – MAJOR GFOLOGIC UNITS, NASSAU COUNTY



Source: U.S. Geological Survey Circular 524, 1966 pumpage is estimated to be 400 million gallons per day (Cohen, et al., 1968; Perlmutter and Koch, 1971). About half is discharged directly to the sea through sewage treatment plants. This amount plus the unrecovered storm runoff constitute a drawdown on the groundwater reservoir that is responsible for falling water tables in some areas and the threat of salt water intrusion from the ocean in others. The restoration of the equilibrium state would appear to require a recycling of pumpage and storm water by means of artificial recharge basins, injection wells, and spray infiltration. But return of the spent waters, consisting of sanitary and industrial effluent, presents the hazard of degrading the water quality. Natural infiltration from cesspools and septic tanks has effected adversely groundwater quality (Smith and Baier, 1969). Water managers, thus, are confronted by two equally unhappy alternatives: (1) a declining supply of potable water, or (2) a steady supply of declining water quality. Technological options available to water managers can be applied to (1) or (2). These options include a mixed strategy of influent treatment before consumption, effluent treatment prior to discharge, and recharge. Desalinization and/or water importation from upstate are other structural alternatives.

Demand reduction, not often mentioned, would require land-use controls and such nonstructural tactics as price regulation to discourage consumption and the banning of products (selected detergents) that yield spent waters containing degrading recalcitrant liquid effluent.

Available data have been used to prepare parameter quality maps of Long Island's groundwater to indicate the spatial and temporal patterns of variation for each of the three main aquifers (Cohen, et al., 1971; Perlmutter and Koch, 1971). Two parameters, nitrate and chloride, were selected to illustrate our findings for the purposes of this report. The latest observation available on the selected parameter at each well screened in a given aquifer was used.

The general descriptive statistics of each parameter and aquifer and their numbers of observations are given in Table 2 for nitrate and chloride. The means of each parameter decrease with depth, as expected. However, the maximum values do not show this relation, indicating that at selected well sites, pollution is higher in the deeper aquifers. This is shown by the occurrence of the highest maximum nitrate value in the Magothy, and the presence of a greater maximum chloride value in the Lloyd than in the Magothy. In the chloride set from the Lloyd the wide range is reflected by the standard deviation.

Isoline maps of each aquifer parameter were prepared by use of an automatic computer mapping routine, SYMAP (Degelman, 1964). The interpolative contouring algorithm takes the values of known data points and produces a smooth surface through the points. The surface represents the trends implied by the point values. The calculation of unknown values on the surface is based on a gravity model using weighted averages and slopes of nereby data points. The computed value at an intervening point is the weighted average of the values at known data points, with the weightings based on the inverse square of the distance. The surface is perfectly reliable only at the known data points, where the error depends on the accuracy of the raw data. If the mapped space has a sparse population of

Table 2. Descriptive Statistics of Nitrate and Chloride in Wells, Nassau County, Long Island

Most recent observation on well parameter, 1952-1970 (data from Dept. of Health, Nassau County)

Parameter	Aquifer	Obs	Mean	S.D.	S.E.	Max.	Min
Nitrate, ppm N	Glacial	18	6.067	4.160	0.981	13.600	0.0
	Magothy	313	2.515	3.485	0.197	20.500	0.0
	Lloyd	40	0.695	1.194	0.189	3.900	0.0
Chloride, ppm Cl	Glacial	18	27.992	33.582	7.915	152.0	6.40
	Magothy	313	9.305	6.452	0.365	49.0	3.0
	Lloyd	40	8.340	11.001	1.740	72.0	0.0

Abbreviations:

Obs, number of wells observed; S.D., standard deviation; S.E., standard error of the mean; Max., maximum value; Min., minimum value raw data points, or, if the values fluctuate widely among the data points, the reliability of the surface is lessened (Shepard, 1967).

The method also has the capability of extrapolating values beyond the polygonal area enclosed by the known data points. The values tend toward a limit near the average of the closest data points. The limit will be above the average if an upward trend is indicated by the data points, or below the average if they show a downward.

Caution must be exercised in evaluating the maps. Each map is no better than the raw data input. Its accuracy also reflects the geographic dispersion of the data points. Some delimited areas may not include any observed well locations. In these areas values of known data points located beyond the area have been extrapolated. Despite these caveats the maps do yield a geographic description of the quality state of an aquifer from the best available information and are suited to the depiction of the spatial variations of continuously distributed groundwater parameters.

The nitrate maps for the Glacial, Magothy and Lloyd aquifers are shown by Figures 2, 3, and 4, respectively. In the Glacial aquifer the nitrate values range from 0 to 13.60 ppm of nitrate, as nitrogen. Eighteen data points were used to construct the map, after the range was divided into five equal class intervals, each interval accounting for 20 percent. Three wells in the fifth class exceeded the nitrate standard of 10 ppm as nitrogen. The map also delimits by extrapolation areas falling in several class intervals.

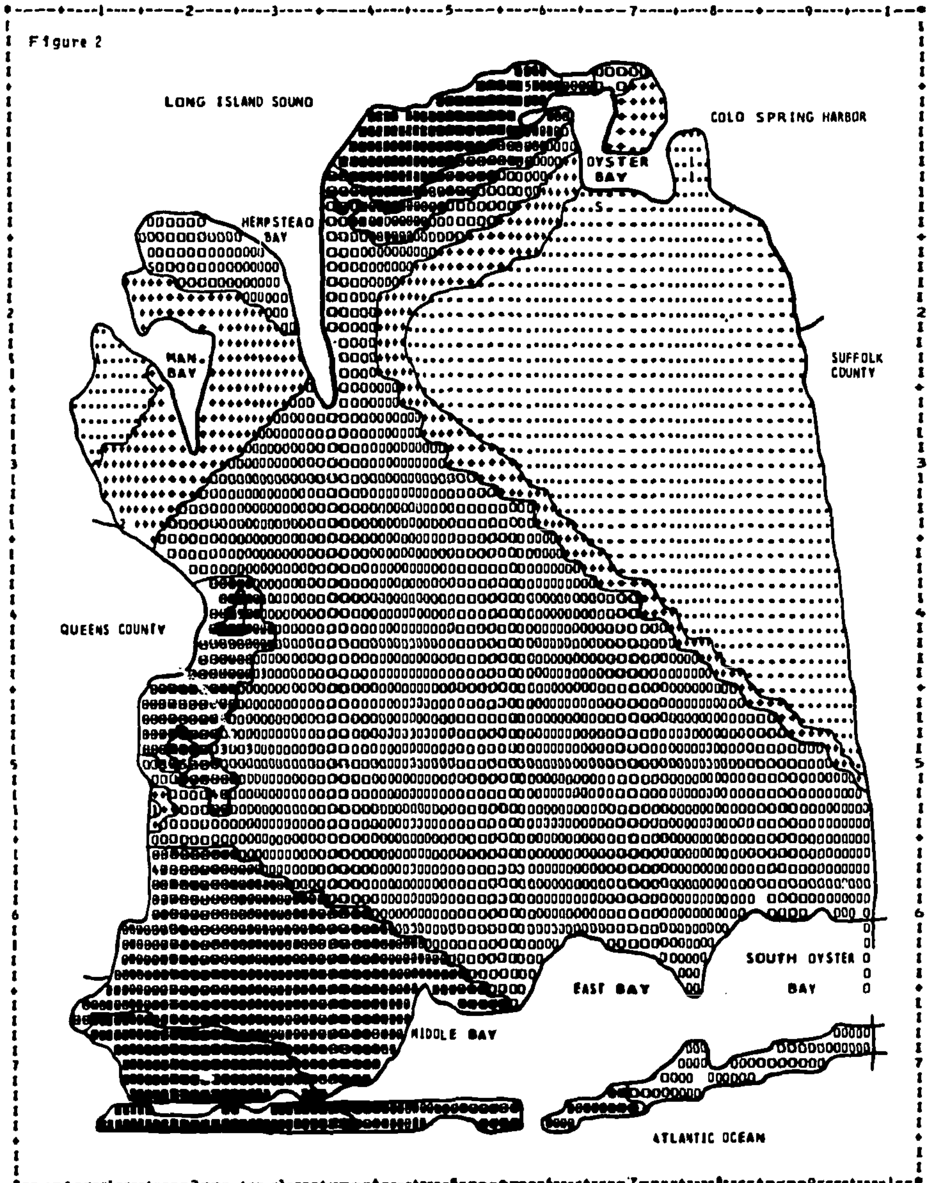
The nitrate map of the deeper Magothy aquifer was based on 313 data points. Nine wells exceeded the standard. Though the range was wider than the Glacial, the areas delimited by the two highest class intervals are small because of the 242 observations in the lowest category. The east-west zone of aquifer deterioration is striking through the central part of the country, where intense development has occurred.

As expected, the deepest Lloyd aquifer shows the smallest range in nitrate values -- 0.0 to 3.90 ppm. None of the observations exceeded the standard. The map was based on 40 data points. Within the narrow range of nitrate values, however, a belt of higher values stands out along the north shore of the county, where the Lloyd aquifer is close to the surface.

The chloride maps of the Glacial, Magothy and Lloyd aquifers are shown by Figures 5, 6 and 7, respectively. The Glacial map was based on 18 data points whose chloride contents ranged from 6.40 to 152.00 ppm. None of the wells exceeded the drinking water standard of 250 mgm per liter. Because of the small number of data points, large areas of the map have been extrapolated to the lowest class interval. The chloride values were highest in the northwestern part of the country.

The deeper Magothy aquifer has a narrower range of chloride values -- 3.00 to 49.00 ppm -- than the Glacial aquifer. The Magothy map was based on 313 well observations. The east-west belt of higher chloride values through the central part of the county is similar to the behavior of nitrate in the Magothy.

Figure 2



SYMAP

3.7 SECONDS FOR MAP

TIME = 45545.7

ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
('MAXIMUM' INCLUDED IN HIGHEST LEVEL ONLY)

MINIMUM	0.0	2.72	5.44	8.16	10.88
MAXIMUM	2.72	5.44	8.16	10.88	13.60

C WELLS, NASSAU COUNTY, LONG ISLAND, NEW YORK

C GLACIAL AQUIFER NO3 PPM,AS N, MOST RECENT OBSERVATION

C NUMBERS ARE WELLS AND CLASS INTERVALS;"S" MEANS
MULTIPLE WELLS

PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL

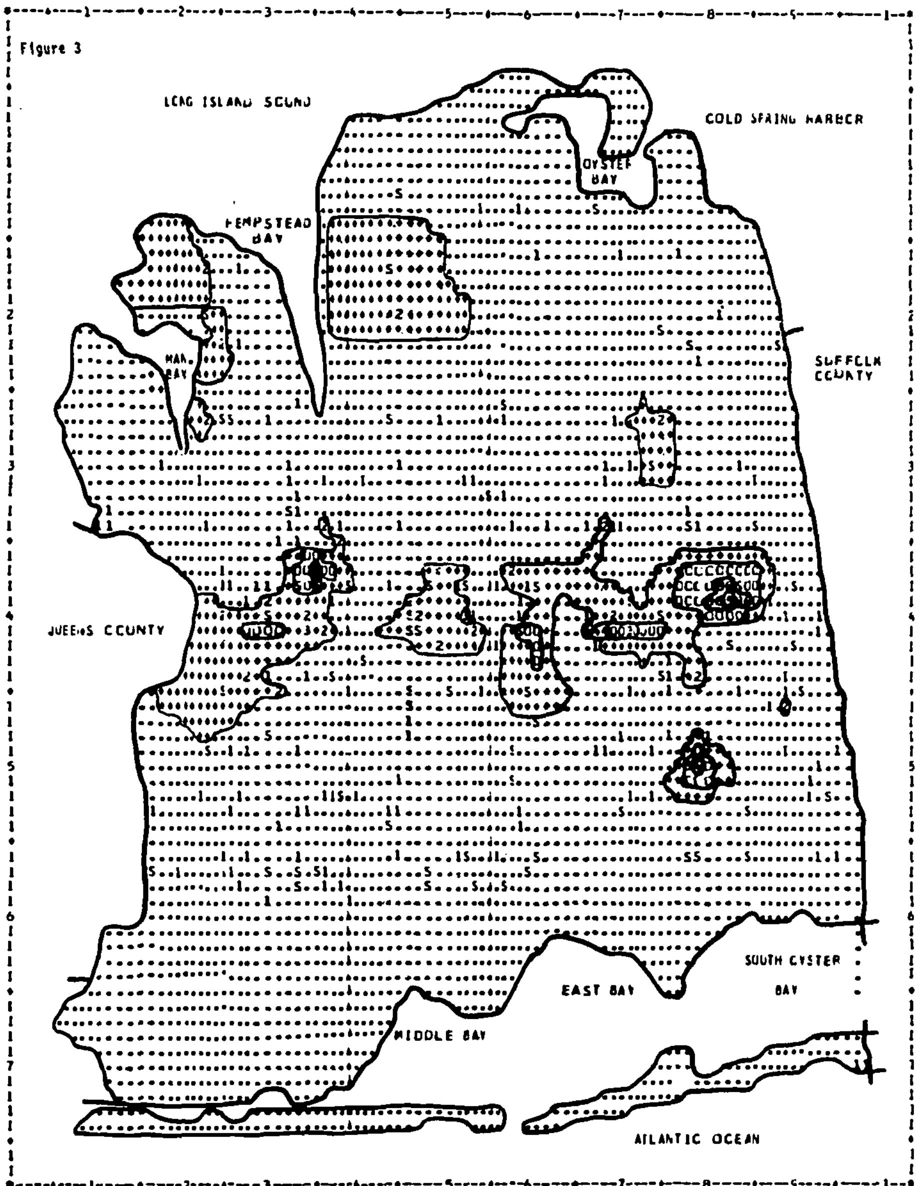
20.00	20.00	20.00	20.00	20.00

DATA VALUE EXTREMES ARE 0.0 13.60

TOTAL SUPERIMPOSED DATA POINTS
IN 2 LOCATIONS.

FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL

LEVEL	1	2	3	4	5
SYMBOLS	1	2	3	4	5
FREQ.	6	2	5	2	3



SYMAP

7.3 SECONDS FOR MAP

TIME = 60916.9

ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
('MAXIMUM' INCLUDED IN HIGHEST LEVEL ONLY)

MINIMUM	0.0	4.10	8.20	12.30	16.40
MAXIMUM	4.10	8.20	12.30	16.40	20.50

C WELLS, NASSAU COUNTY, LONG ISLAND, NEW YORK

C MAGOTHY AQUIFER NO3 FIM,AS N. MOST RECENT OBSERVATION

C NUMBERS ARE WELLS AND CLASS INTERVALS;"S" MEANS MULTIPLE WELLS

PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL

20.00	20.00	20.00	20.00	20.00

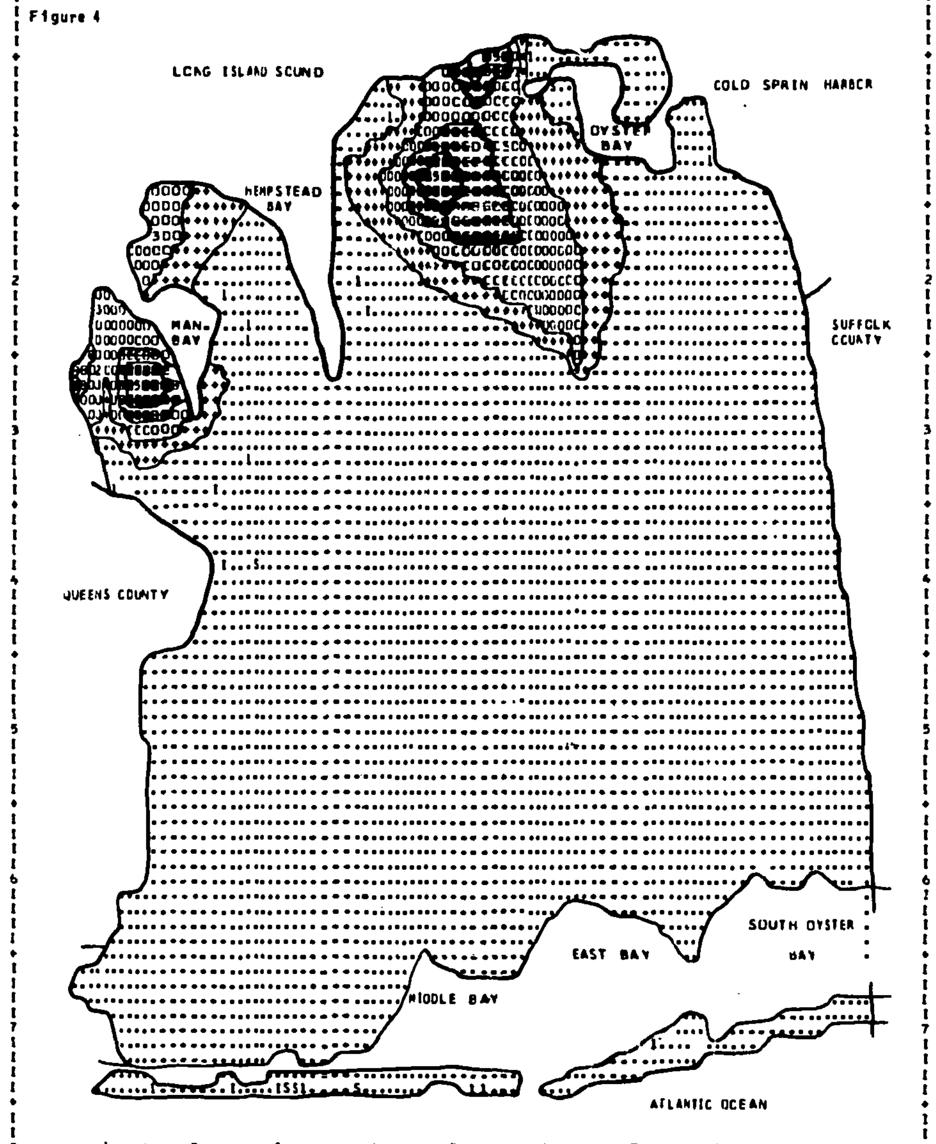
DATA VALUE EXTREMES ARE 0.0 20.50

TOTAL SUPERIMPOSED DATA POINTS OCCUR IN 66 LOCATIONS.

FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL

LEVEL	1	2	3	4	5
SYMBOLS	....1....	++++2++++	CCCC3CCCC	0000400000	5
FREQ.	242	50	12	6	9

Figure 4



SYMAP

4.4 SECONDS FOR MAP

TIME = 45600.3

ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
('MAXIMUM' INCLUDED IN HIGHEST LEVEL ONLY)

MINIMUM	0.0	0.78	1.56	2.34	3.12
MAXIMUM	0.78	1.56	2.34	3.12	3.90

C WELLS, NASSAU COUNTY, LONG ISLAND. NEW YORK

C LLOYD AQUIFER NO3 PPM, AS N, MOST RECENT OBSERVATION

C NUMBERS ARE WELLS AND CLASS INTERVALS;"S" MEANS MULTIPLE WELLS

PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL

20.00	20.00	20.00	20.00	20.00

DATA VALUE EXTREMES ARE 0.0 3.50

TOTAL SUPERIMPOSED DATA POINTS IN 6 LOCATIONS.

FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL

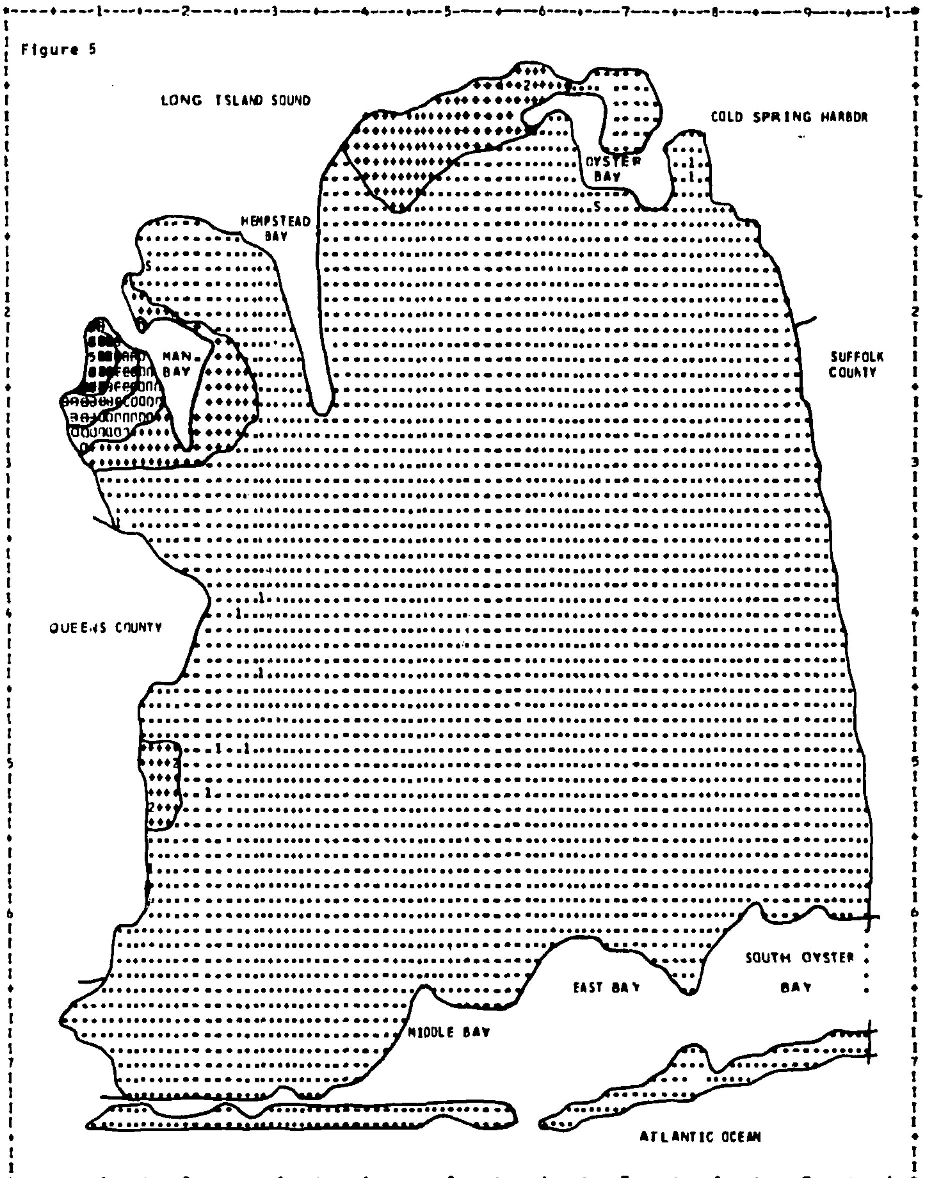
LEVEL	1	2	3	4	5
SYMBOLS	....1....	++++2++++	OOOO3OOOO	ΘΘΘΘ4ΘΘΘΘ	■■■■5■■■■
FREQ.	31	1	3	1	4

The Lloyd aquifer was mapped from 40 data points, whose chloride values ranged from 0.0 to 72.0 ppm's. The highest values were observed in the northwestern part of the country.

Wells containing concentrations of nitrate and chloride exceeding those plotted on the maps have been reported (Perlmutter and Koch, 1971; De Luca, et al., 1965). These data were not included in the well set made available to us and used in our study.

The general spatial distribution of the entire well set is shown by Figure 7 , Chapter I. The locations appear to provide good areal coverage. However, when the wells are sorted by aquifer and plotted on maps, it is apparent that their geographical distributions are highly irregular and poorly suited to the monitoring of groundwater quality. As a result, the automatic mapping routine was forced to extrapolate the values of a limited number of data points to large areas without observations. The sparsity of data points and their spatial maldistribution are surprising in view of the total dependence of Nassau County on groundwater. A statistically-designed population of sampling points would provide water managers with more reliable information than the present spatial patterns, which probably evolved haphazardly as supply wells were brought into production in response to water needs.

The pollution maps generated by SYMAP are based on the most recent observations at the wells. Intervening values are not produced by a diffusion model simulating the distribution of quality parameters introduced into the aquifer from point sources, or, for chlorides, from saline intrusion. Present understanding of the diffusion processes of specific parameters emanating from multiple punctiform or saline sources and moving through the varying porous media of aquifers, is too limited for the construction of such models, though a beginning has been made to describe their behavior on Long Island (Lauman Company Report, 1969). However, quality parameter levels have been predicted for specific wells by extrapolating the historic record at the well into the future, after the rejection of extreme values. Because of the limited length of record, the extrapolated trend lines have been based on a small number of observations. For nitrates, the predictions indicate that 53 wells will exceed the standard by 2020 (Smith and Baier, 1969). The underlying assumption in extrapolation, of course, is that historic parameter-aquifer behavioral relations will continue unchanged through the projection period.



SYMAP

3.8 SECONDS FOR MAP

TIME = 44842.8

C WELLS, NASSAU COUNTY, LONG ISLAND, NEW YORK

C GLACIAL AQUIFER CL PPM MOST RECENT OBSERVATION

C NUMBERS ARE WELLS AND CLASS INTERVALS;"S" MEANS MULTIPLE WELLS

DATA VALUE EXTREMES ARE 6.40 152.00

TOTAL SUPERIMPOSED DATA POINTS OCCUR IN 2 LOCATIONS.

ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
('MAXIMUM' INCLUDED IN HIGHEST LEVEL ONLY)

MINIMUM	6.40	35.52	64.64	93.76	122.88
MAXIMUM	35.52	64.64	93.76	122.88	152.00

PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL

20.00	20.00	20.00	20.00	20.00

FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL

LEVEL	1	2	3	4	5
SYMBOLS	....1....	++++2++++	000030000		
FREQ.	14	3	0	0	1

- 125 -

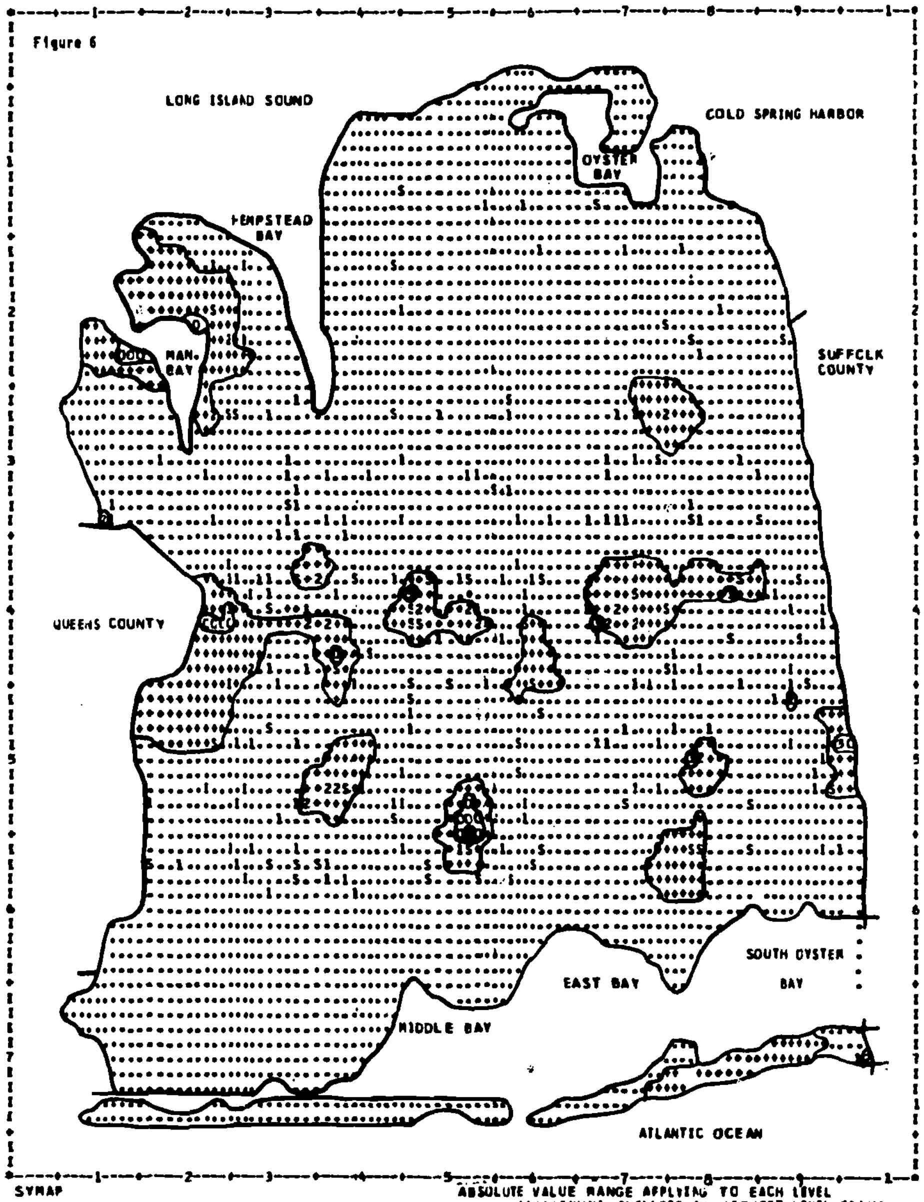


Figure 6

SYMAP

7.5 SECCNCS FCP MAP

TIME = 45326.2

C WELLS, NASSAL COUNTY, LCNG ISLAND, NEW YCRK

C MAGOTHY AQUIFER CL PPM, MOST RECENT CBSERVATION

C NUMBERS ARE WELLS AND CLASS INTERVALS;"S" MEANS MULTIPLE WELLS

DATA VALUE EXTREMES ARE 3.00 49.CO

TOTAL SUPERIMFCSEC CATA PCINTS OCCUR IN 66 LOCATICNS.

- 126 -

ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL
('MAXIMUM' INCLUDEC IN HIGHEST LEVEL CNLY)

MINIMUM	3.0C	12.20	21.40	30.60	39.8C
MAXIMUM	12.20	21.40	30.60	39.80	49.00

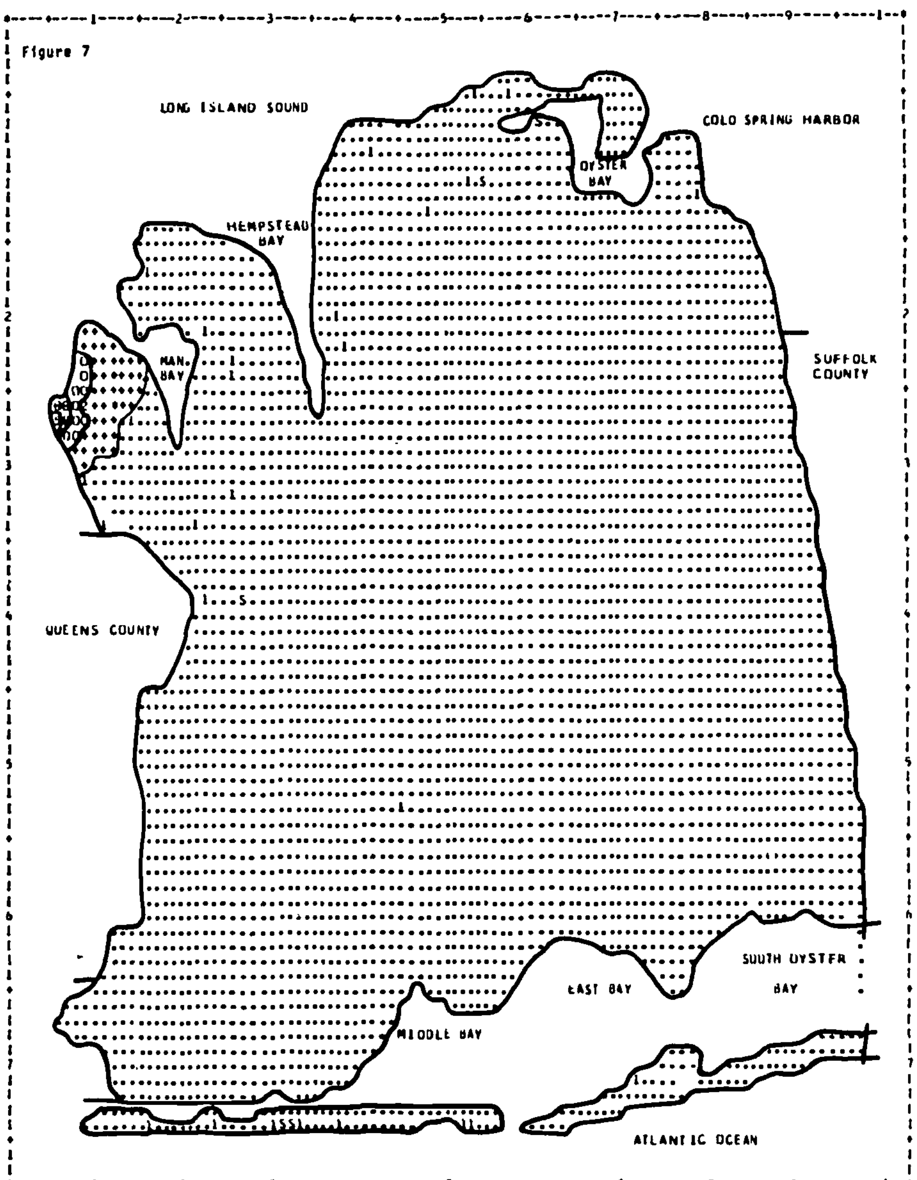
PERCENTAGE OF TOTAL ABSOLLTE VALUE RANGE APPLYING TC EACH LEVEL

20.CO	2C.CO	20.00	20.00	2C.0C

FREQUENCY DISTRIBUTICN OF CATA PCINT VALUES IN EACH LEVEL

LEVEL	1	2	3	4	5
SYMBOLS	....1....	++++2++++	CCC03000C		
FREQ.	249	46	9	3	2

Figure 7



SYMAP

3.7 SECONDS FOR MAP

TIME = 45803.0

C WELLS, NASSAU COUNTY, LONG ISLAND, NEW YORK

C LLOYD AQUIFER CL PPM, MOST RECENT OBSERVATION

C NUMBERS ARE WELLS AND CLASS INTERVALS;"S" MEANS MULTIPLE WELLS

DATA VALUE EXTREMES ARE 0.0 72.00

TOTAL SUPERIMPOSED DATA POINTS - 127 -

OCCUR IN 5 LOCATIONS.

ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL ('MAXIMUM' INCLUDED IN HIGHEST LEVEL ONLY)

MINIMUM	0.0	14.40	28.80	43.20	57.60
MAXIMUM	14.40	28.80	43.20	57.60	72.00

PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL

20.00	20.00	20.00	20.00	20.00

FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL

LEVEL	1	2	3	4	5
SYMBOLS	....1....	++++2++++	OOOO3OOOO	ØØØØ4ØØØØ	■■■■5■■■■
FREQ.	38	1	0	0	1

CHAPTER IV

SCREENING OF THE HYDROLOGIC DATA: THE ESTUARY

A. Data Reduction

The initial data set on the estuary was very large, amounting to one-and-a-half million bits of information. However, poor coordination among the subsets limits its value. The sheer mass required simplification in order to prepare an estuarial water-quality map. Data reduction was accomplished in several steps:

1. Of the original 876 stations, 445 (51%) were discarded because of poor information, leaving 431 stations with data on 20 parameters distributed among the stations. The time span was limited to the summer months because of the emphasis on recreational uses.

2. Although reduced, the pool of data was still too cumbersome. Accordingly, a central-tendency measure to be used in lieu of the raw observation was derived for each variable for each station. The usefulness of several measures was reviewed (mean, mode, standard deviation, skewness, and kurtosis) for each variable.* The mean score turned out to be the most applicable as the "raw" data for all subsequent analyses.

3. Variables represented on less than 30 stations were excluded.

4. A Pearson product-moment correlation matrix was computed, deleting variables with less than 15 observations.**

5. The data were reduced further by using the correlation matrix as input to a principal-components factor analysis, subsequently rotated in order to identify the most important variables from their loadings on the factors. The results are given in Table 1 with the most important variables underscored.

   Although factor analysis is most often used as a descriptive statistic, it has also been used to identify a variable representative of the variable structure of a particular factor. Greenberg and Boswell (1972) have shown that the amount of explanation does not significantly decrease when the total amount of variables is decreased.

6. The selection of the most representative variable for each factor was based on three criteria which were not

---

*The screening program used is called DISTAT and is described in Veldman, 1967.

**The only exception was carbon and phenol, for which nine observations were used.

necessarily mutually exclusive. First, no variable was selected which had a factor loading less than .70, accounting for some 50 percent of the total variance of the variables on the factor. Six variables (ortho-phosphate, carbon, Kjeldahl nitrogen, COD, turbidity in Jackson Units, and BOD) did not load on any of the rotated factors and were eliminated from further consideration. The factor analytic model did not explain their variances.

Secondly, where several variables loaded on a specific factor the variable with the highest loading was selected. Two exceptions were made to this rule based on the principle that the variable selected had to be recognized as a pollutant. The two variables excluded were air temperature and chlorides. The latter variable is a measurement of the salt content of the water which is of significance if one wants to relate the dynamic behavior of the estuary, especially the tidal action, with any number of independent water quality variables. For reasons discussed previously, a dynamic cause-and-effect study was not the objective. Air temperature was also dismissed, even though it loaded quite highly on the first factor, as its influence on the water quality was considered marginal.

The third and final consideration made in the selection of variables for mapping purposes was the number of stations from which the variable had been collected.

Seven factors with eigenvalues equal to or exceeding 1.0 were rotated. Factor I contained three variables: air temperature (already discussed), ammonia and phosphates -- two nutrients which have been identified as catalysts in the process of eutrophication of fresh as well as tidal waters. The number of stations at which the two nutrients were measured amounted to 55 in the case of ammonia, and 68 for phosphates. Since phosphates loaded significantly higher on this factor it was decided to map this variable as representative of Factor I.

Three variables loaded on Factor II. Although both membrane filter Coliform and Streptococci bacteria loaded higher than DO (.88, .86 and -.75 respectively), it was decided to map DO, partly because 250 stations were available for it, as against 152 and 144 in the cases of Coliform and Streptococci bacterial counts. More importantly, however, the selection of DO was clear cut because considerable doubt has been cast in recent years against the use of the bacterial counts as indicator variables for pathogens (Flynn, 1964; Muss, 1963; Public Health Activities Committee, 1963; Gallagher and Spino, 1968).

Table 1. Rotated Factor Structure 20 Variables

Variable	Factors 1	2	3	4	5	6	7
Air Temperature	.84	.05	-.23	.08	-.21	.00	-.10
Water Temperature	.31	.26	.01	.03	.15	.38	.72
pH	.14	-.35	.77	-.14	-.09	-.08	-.05
DO	.28	-.75	.31	.09	-.11	.00	-.11
BOD	.39	.40	.67	-.03	.01	-.07	.03
Chlorides	.04	.02	.04	.04	.17	.14	-.90
Conductivity	.18	.02	.08	-.08	.55	-.71	-.10
Turbidity J.U.	.16	.52	-.16	.08	-.26	.55	.10
Nitrite	.17	-.30	.03	-.71	.37	-.15	-.01
Nitrate	.23	.12	.15	-.90	-.12	.19	.04
COD	.32	.14	-.11	.51	.58	-.02	-.28
M.F. Coli	.01	.88	.12	.20	.11	.08	.07
M.F. Fecal Coli	.02	.86	-.03	.07	.12	-.09	-.03
M.F. Streptococci	.07	.26	-.06	-.06	.70	.05	-.01
N. Kjeldahl	.36	.52	.33	.52	.13	.48	.14
Carbon	.50	.28	.36	-.20	-.34	.54	.46
Ammonia	.78	.42	.23	.36	.06	.20	.29
Phenols	.02	.16	.05	.12	-.26	-.88	.10
Phosphates	.99	.05	.15	-.07	.10	.16	.28
Ortho Phosphates	.60	.65	.22	-.28	.22	.04	.19
Cumulative Proportion of Total Variance	.18	.32	.45	.57	.65	.77	.87
Eigenvalues	3.57	3.87	1.64	2.20	1.74	2.41	1.90

Two variables -- pH and BOD -- loaded on Factor III; pH was selected as the one with the highest loading even though it was represented in only 192 stations as opposed to 228 stations in the case of BOD.

Factors IV and V were represented by only one variable each, Nitrate and Streptococci, respectively. These two variables also were mapped.

The final two rotated factors (VI and VII) each had two variables with loadings in excess of .7. In the case of Factor VI, phenols were selected over the measure of conductivity. This decision was made in part because of the higher loadings for phenols even though it meant reducing the numbers of stations from 109 in the case of conductivity to 42 for phenols, and, in part, because phenols are a pollutant most often associated with the oil and chemical industry whereas conductivity is a composite measure related to the ions in the respective water body. No variables were selected from Factor VII. Only two variables (water temperature and chlorides) loaded highly on this factor. Except in extreme instances, water temperature in itself cannot be considered a pollutant. Its effect on water quality is related to the DO content previously discussed. The chloride count measures the saltiness of the water body and is directly related to the tidal effect. This variable was not mapped because it was not considered an important water-quality estuarial variable. The inverse relationship between the two variables loading on Factor VII is to be expected in view of their origins. Higher temperature is to be expected in smaller water bodies which are relatively less dynamic, whereas higher chloride readings are predictable in more open water bodies.

7. Since only six variables were selected, the station population was reduced by an additional 74 stations. This reduction was caused by the incomplete coverage of all 20 variables for all 431 stations.

B. <u>Geographic Patterns</u>

Since a number of maps were to be generated covering the same base area it was decided to utilize the SYMAP routine (Degelman, 1969). This is a computer program which consists of a series of mapping options particularly suitable for projects mapping several characteristics of the same area.*

*The SYMAP program has been used in a number of planning projects in recent years. As examples of this approach see Michael Chubb, "Outdoor Recreation Planning In Michigan By a Systems Analysis Approach Pt. III, The Practical Application of Program Recsys and Symap," Michigan Department of Conservation Technical Report No. 12, Michigan Department of Conservation, Lansing, Michigan, December, 1967.

Unfortunately no chart exists covering the whole New York-New Jersey Metropolitan Estuary on a suitable scale. This meant that the estuary had to be broken down into a number of smaller areas which were then mapped and reduced to a common scale of 1:40,000.*

The standardization of the maps required 16 smaller maps to be created partly because of the problem of differing scales and partly because of size limitations imposed by the SYMAP program itself.

Following the creation and testing of the outline of the submaps, the stations covering the six selected variables were mapped.** In a number of instances a location had been sampled by several different agencies within the period under investigation. In such instances the locations of these stations were altered by changing their coordinate location by .01. Such small changes, as far as the computer is concerned, would recognize each station as an independent location. This is an important consideration for the purpose of interpolation of the isoline maps, yet these changes would in no way alter the location of the station on the printed output map.***

Although considerable thought was given to selecting those variables which had been collected at the greatest number of stations within the estuary, uniform coverage could not be obtained (Table 2). The six variables drawn from the 357 stations were represented in the research area as indicated in Table 3. It will be noted that near-universal coverage existed for DO and pH. Each variable is deficient in one area (Long Island Sound - Mamaroneck and Hudson River - Newburgh respectively). The following three variables -- nitrate, phosphate and Streptococci bacteria -- are moderately represented with four, five and six areas totally missing stations representing them. Finally, phenols are represented in only four areas indicating the relatively recent emphasis accorded this variable by estuarial agencies.

The stations depicting the distribution of the six selected variables also verify the notion that the eastern section of the estuary is the area which is most heavily researched, even though its utilization for recreational purposes is least. Data covering phenols have been collected only in the core area comprising the upper Harbor, Raritan Bay, Kill van Kull and Arthur Kill and Newark Bay. The areas studied for phenols also coincide with that part of the estuary which has the highest density of stations.

*The U.S. Coast and Geodetic Coastal Charts varied from 1:40,000 to 1:10,000. Small-scale maps of a scale of 1:80,000 do in fact exist covering the whole region. Had these been used, too much information would have been lost in terms of the location of the survey stations.

**The station set on which the variable selection was made covered 431 stations. This set was reduced by 74 stations as explained above. The station set from which the maps were drawn included 357 stations. The number of stations used for the individual maps were in all instances less than 357 because no variable had been collected from all stations.

***It should be noted that these changes occurred entirely within the actual sampling area during the sample process, particularly if it was taken from a boat. Changes are the result of wind and currents moving the boat during the sampling period and of human errors introduced by the sampler (field man) himself.

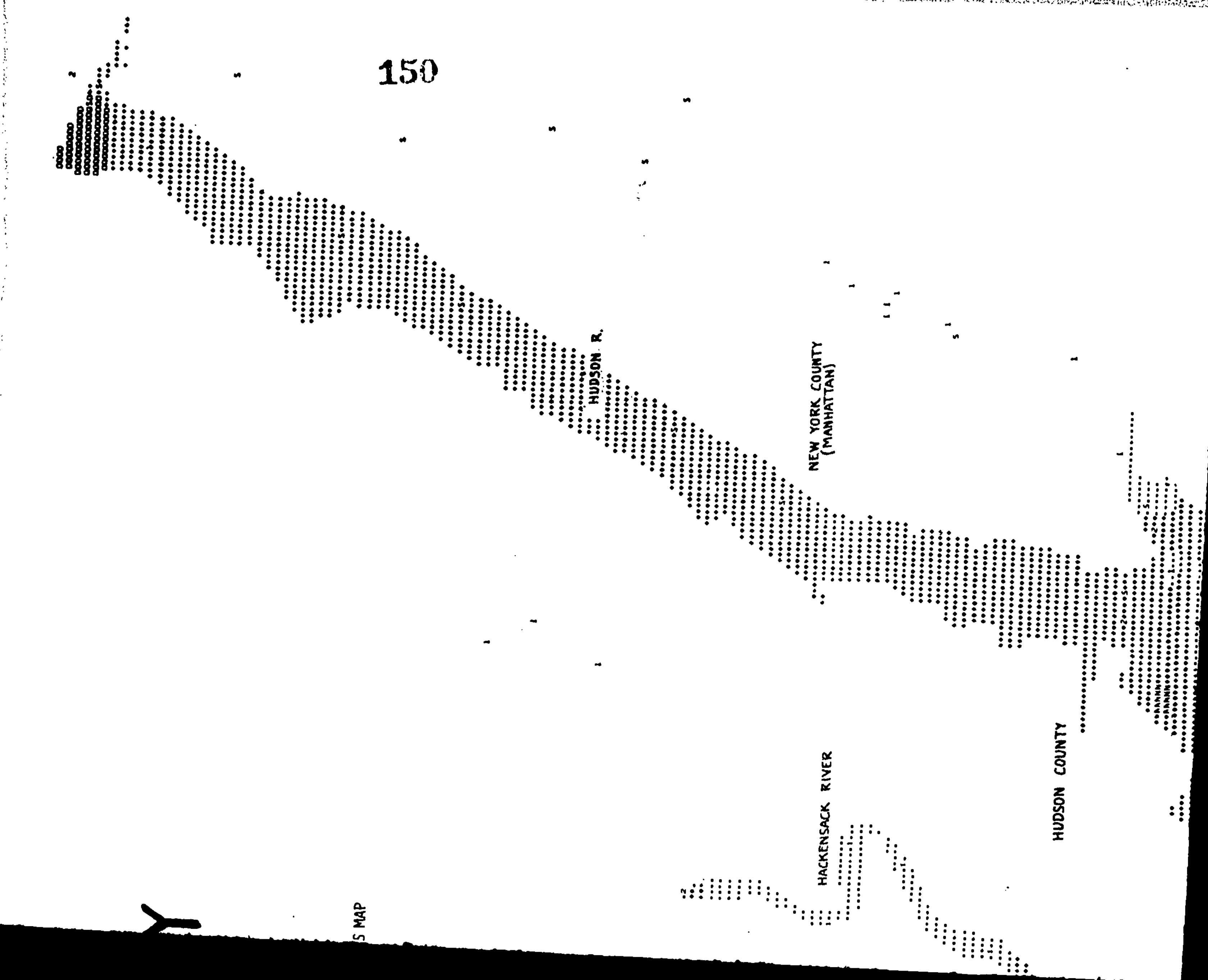
Table 2. Stations by Subareas of the N.Y.-N.J. Metropolitan Estuary

Variable	1	2	3	4	5	6	Subareas 7	8	9	10	11	12	13	16	17	18	Total No. of Stations
DO	35	80	60	39	15	31	10	10	24	6		3	2	6	5	3	329
pH	25	37	42	24	7	15		3	11	6	8	9	13	2	3	1	206
Phosphates	11	9	8	19	5	3		5	12	3		3	4		1	1	84
Strep.	13	70	40	4	5	3		5	11	3				2	3	1	160
Phenols	8	9	18	22													57
Nitrate	13	27	23	21	5	3		5	11	2		3	4	2	3	1	123
	Upper Harbor	Raritan Bay	Kills	Newark Bay	Lower Hudson	Tappan Zee	Newburgh	West Long Island Sound	East River	Eastchester Bay	Long Island Sound - Mamar.	Stamford	Greenwich	Jamaica Bay East	Jamaica Bay West	Rockaway	

The sum of stations representing each variable exceeds the total appearing in Table 15 (first chapter) because a number of stations were counted as belonging in more than one map. The perimeter of each mapped area was included in two or more maps due to overlap.

Table 3. Range and Class Intervals of Mapped Variables

Variable	Class I		Class II		Class III		Class IV		Class V		Range	
DO	.80	2.69	2.69	4.59	4.60	6.49	6.50	8.39	8.40	10.30	.80	10.30
pH	6.90	7.25	7.26	7.61	7.62	7.97	7.98	8.33	8.34	8.70	6.90	8.70
Nitrate	.04	.18	.19	.34	.35	.49	.50	.64	.65	.80	.04	.80
Phosphate	.18	1.43	1.44	2.70	2.71	3.96	3.97	5.23	5.24	6.50	.18	6.50
Streptococci	6	2510	2511	5015	5016	7521	7522	10026	10027	12533	6	12533
Phenols	.01	.86	.87	1.72	1.73	2.57	2.58	3.43	3.44	4.33	.01	4.30


HUDSON R.
NEW YORK COUNTY
(MANHATTAN)
HACKENSACK RIVER
HUDSON COUNTY

NEW YORK-NEW JERSEY ESTUARY

DISSOLVED OXYGEN, MEAN VALUES, 1957-1970

(TIME PERIOD VARIES AMONG STATIONS-SEE TEXT)

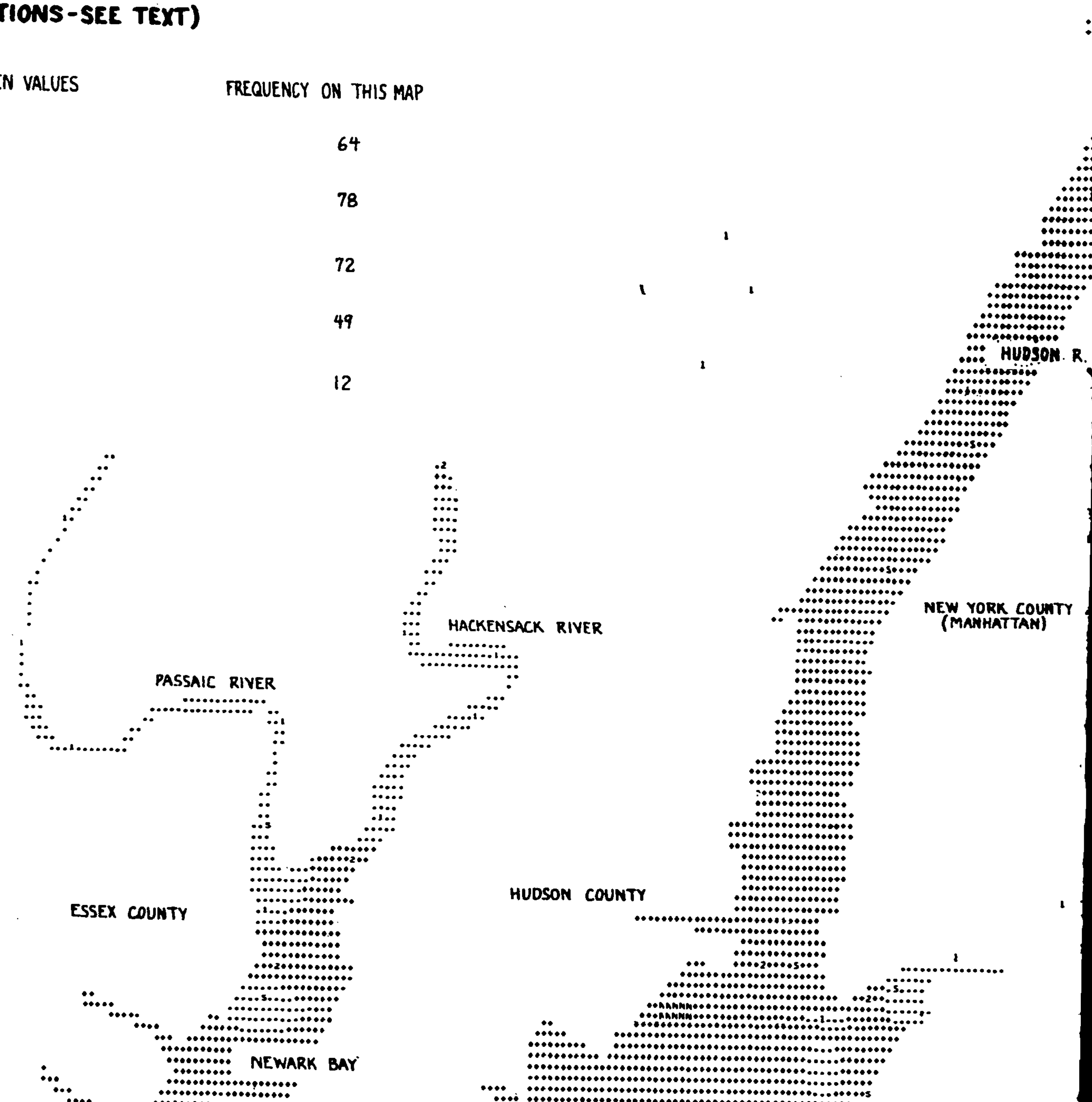
DATA CLASS-INTERVALS	SHADING	MEAN DISSOLVED OXYGEN VALUES (PARTS PER MILLION)	FREQUENCY ON THIS MAP
1		0.80 - 2.70	64
2		2.70 - 4.60	78
3		4.60 - 6.50	72
4		6.50 - 8.40	49
5		8.40 - 10.30	12

THE LOWEST VALUE IN THE AREA MAPPED IS 0.80 P.P.M., THE HIGHEST IS 10.30 P.P.M. THIS RANGE OF VALUES IS DIVIDED INTO FIVE EQUAL CLASS-INTERVALS.

CLASS-INTERVAL NUMBERS (1, 2, 3, 4, 5) MARK LOCATIONS AND SHOW VALUES AT SAMPLING STATIONS.

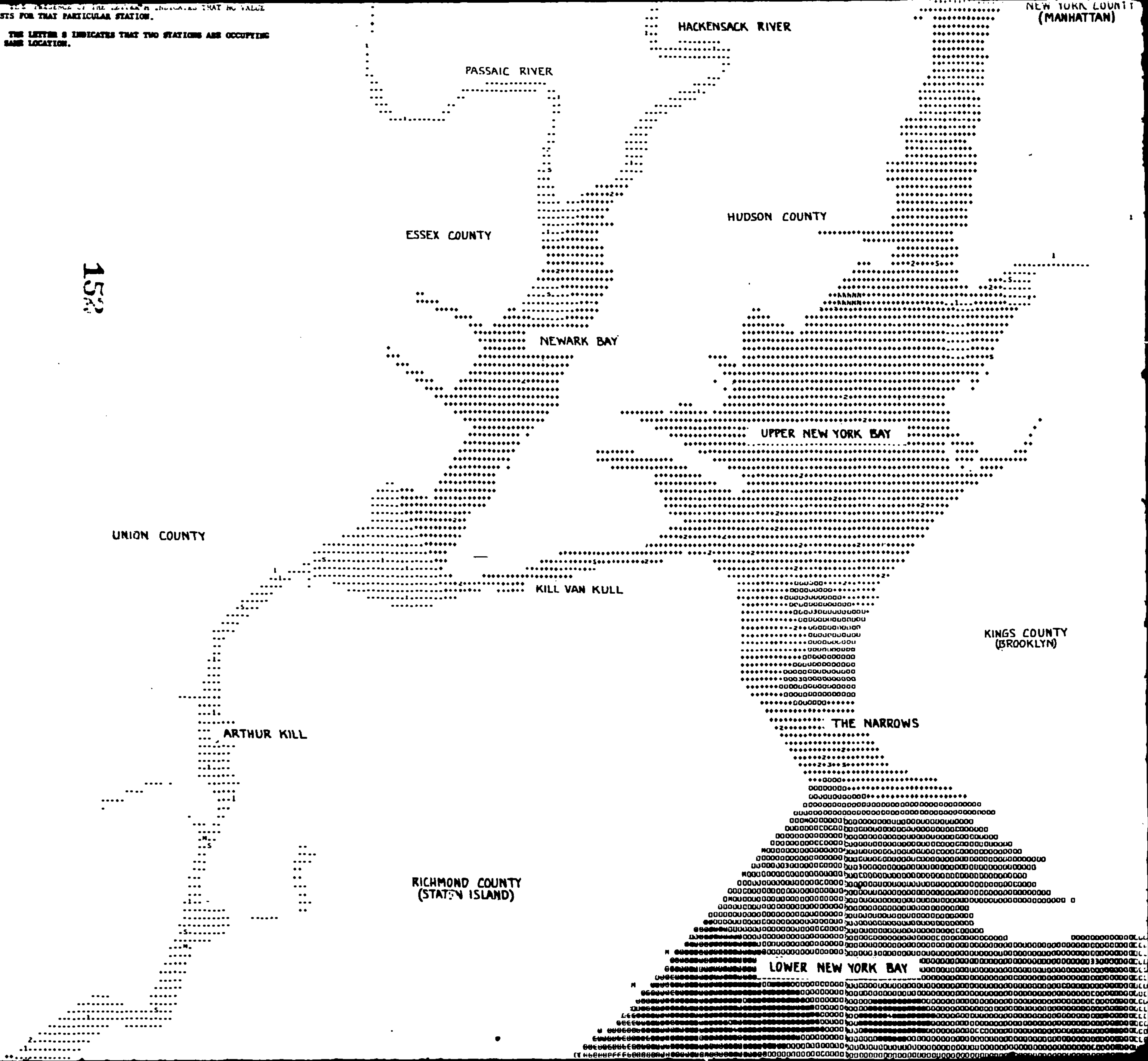
THE PRESENCE OF THE LETTER M INDICATES THAT NO VALUE EXISTS FOR THAT PARTICULAR STATION.

THE LETTER S INDICATES THAT TWO STATIONS ARE OCCUPYING THE SAME LOCATION.



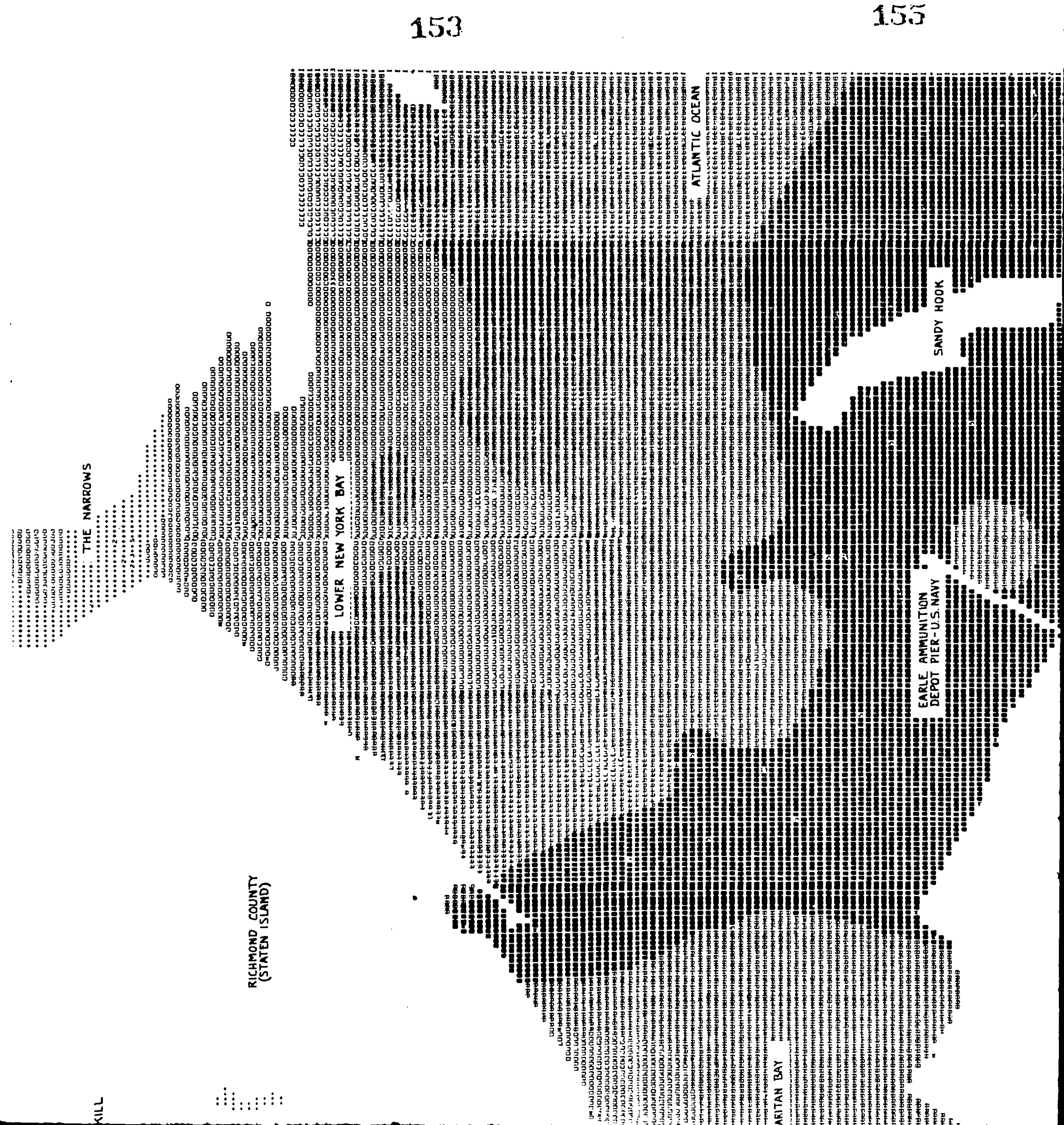
THE PRESENCE OF THE LETTER N INDICATES THAT NO VALUE EXISTS FOR THAT PARTICULAR STATION.

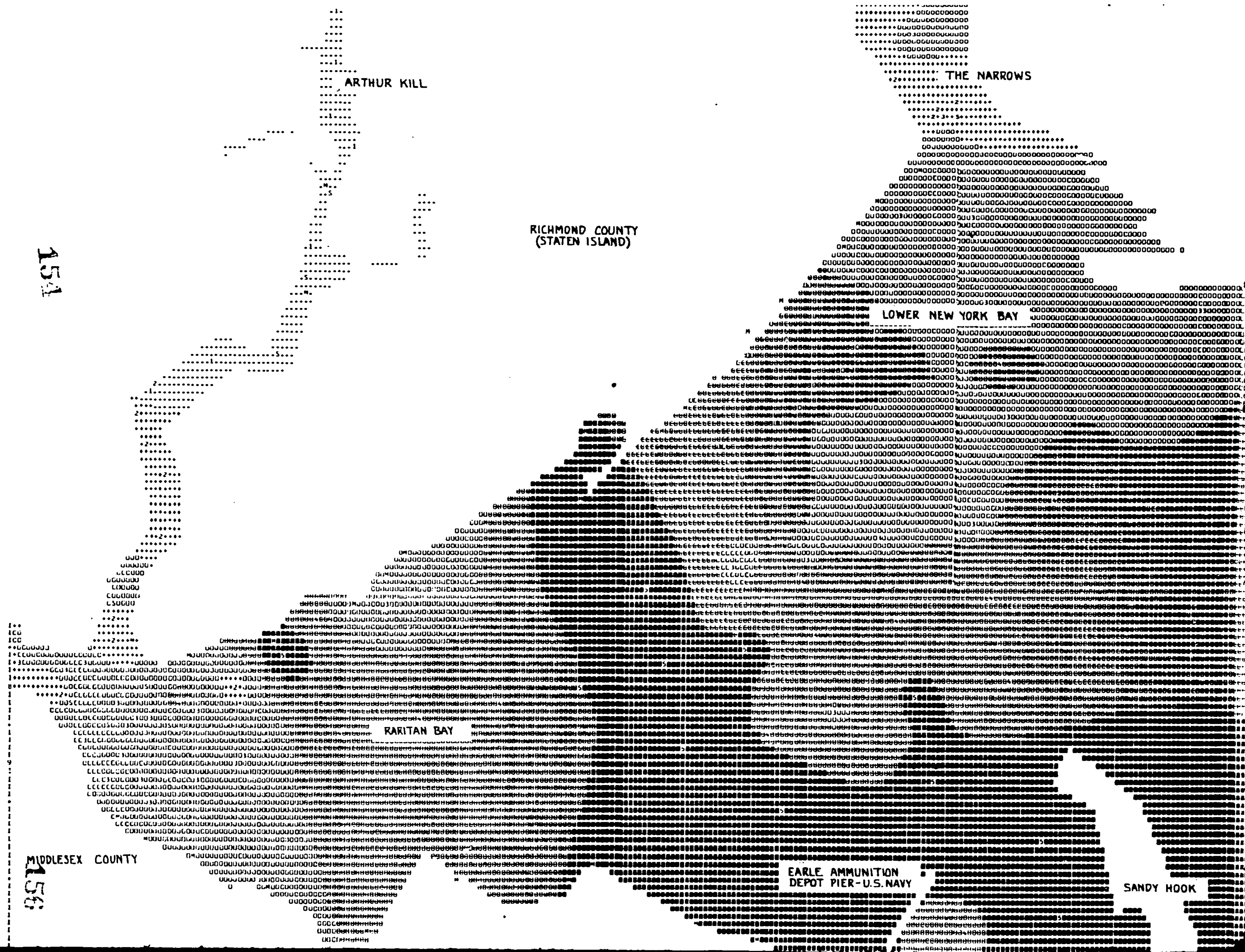
THE LETTER S INDICATES THAT TWO STATIONS ARE OCCUPYING THE SAME LOCATION.



152

154


153
155
THE NARROWS
LOWER NEW YORK BAY
ATLANTIC OCEAN
SANDY HOOK
EARLE AMMUNITION
DEPOT PIER-U.S. NAVY
RICHMOND COUNTY
(STATEN ISLAND)
ARITAN BAY
KILL



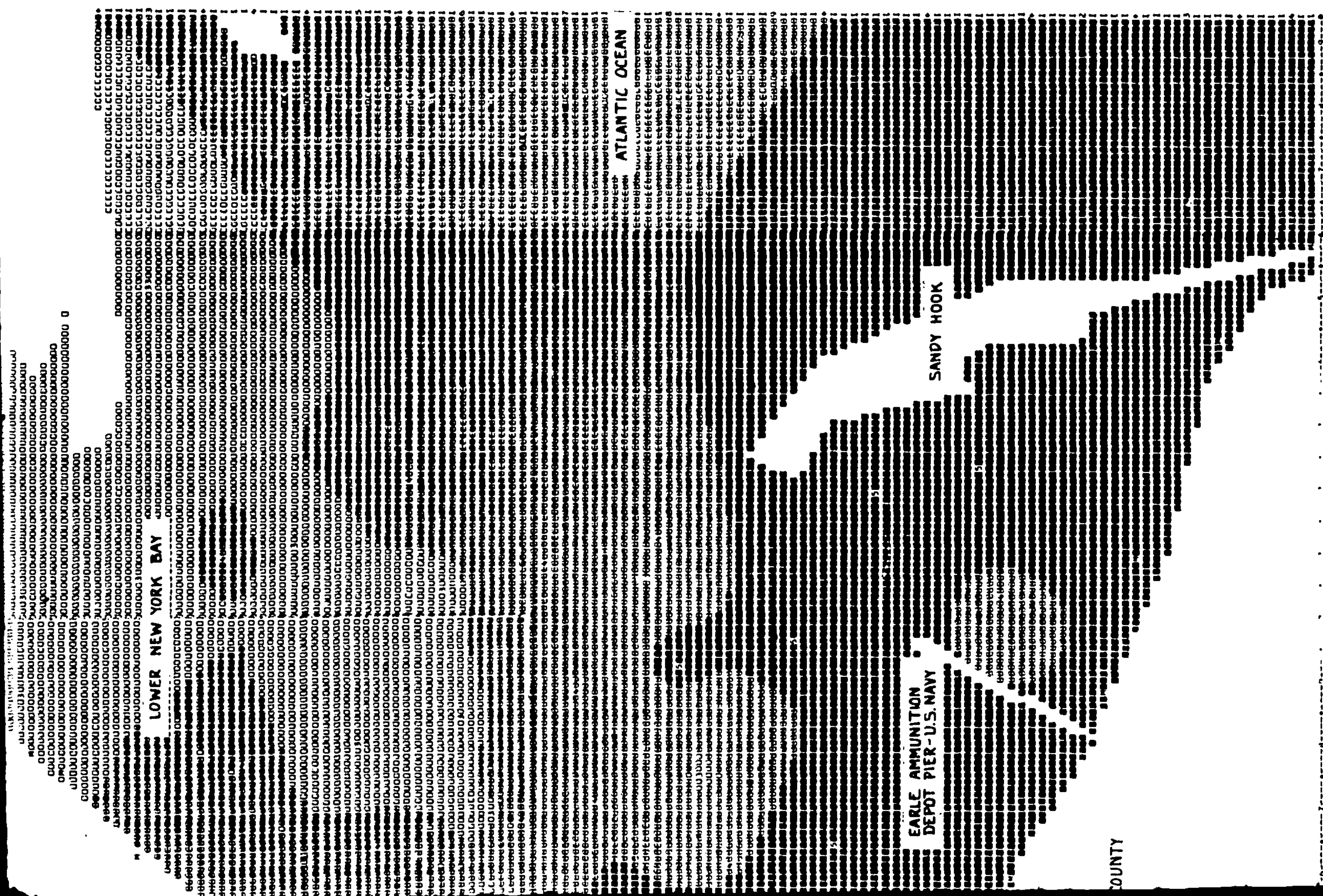
ARTHUR KILL
THE NARROWS
RICHMOND COUNTY
(STATEN ISLAND)
LOWER NEW YORK BAY
RARITAN BAY
MIDDLESEX COUNTY
EARLE AMMUNITION
DEPOT PIER-U.S. NAVY
SANDY HOOK

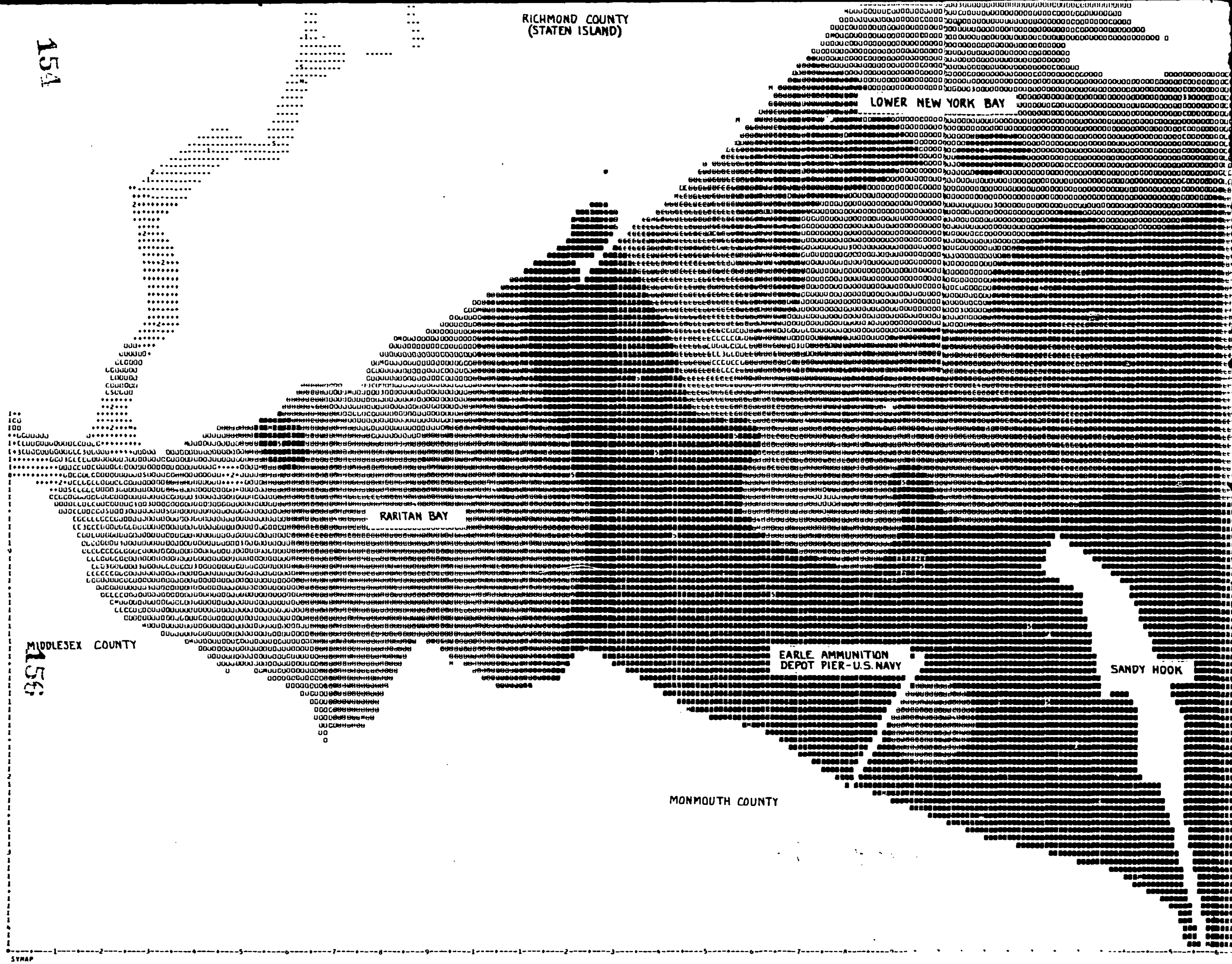
154

156

153

155


LOWER NEW YORK BAY
ATLANTIC OCEAN
SANDY HOOK
EARLE AMMUNITION
DEPOT PIER-U.S. NAVY


RICHMOND COUNTY
(STATEN ISLAND)
LOWER NEW YORK BAY
RARITAN BAY
MIDDLESEX COUNTY
EARLE AMMUNITION
DEPOT PIER-U.S. NAVY
SANDY HOOK
MONMOUTH COUNTY
SYMAP

The total range of the values for each variable was divided into five classes, which constituted the intervals on the isoline maps. Those stations which did not represent the variable were not included in the computation of the maps. In addition, all stations were identified by their respective number in the final map showing the outline of each of the submaps drawn.*

Based on the data reduction discussed above, a total of 68 sectional maps were created covering DO, pH, phosphate, nitrate, Streptococci and phenols.**

Though the values depicted are derived values obtained from a specific part of the estuary (surface) and cover only part of the year (May through September), these maps reveal some interesting relationships. The water-quality conditions in Raritan Bay are of particular significance. This part of the estuary receives water from three major sources: (a) the Raritan River, (b) the Hudson River, and (c) the southern part of Kill van Kull which drains, in part, Newark Bay, and with it the Hackensack and Passaic Rivers. Another major source of water enters the Bay in the form of the six-hour tidal cycle. Jeffries (1962) has shown how tidal waters enter the Raritan Bay from the northeast "while river water moves seaward along the south shore of the Bay." According to this same source, "mixing occurs along the long axis of the Bay."

As shown by Figure 1, the maps, based on data collected over the previous ten-year period, indicate that a high ridge of DO, ranging from 7.3 to 9.2 ppm, persistently divides the Bay into eastern and western sectors, the qualities of which are significantly lower than the central portion of the Bay. It should be remembered, however, that the present map shows surface conditions while Jeffries discusses the total movement of the waters within the Bay. Saline water is more dense than fresh water, and, thus, there would be a tendency for the saline water to enter the Bay in the lower parts of the water column.

The map verifies the findings of Walker (1967), who observed that dyes released just south of the Outerbridge Crossing Bridge in the Arthur Kill

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*The number and size of the interval could have been changed. If one were interested in viewing each submap independently, the intervals could have been based exclusively on the values falling within that particular area. Another alternative would have been to devise the intervals on the basis of the number of stations. If five classes were required, each interval would consist of 20 percent of the total number of stations. Using this method, greater visual variety would be created since the classes would be based on the number of stations and not on the actual range of the distribution. (It is estimated that approximately three hours of computer time would be required to have the maps rerun.)

**Figure 21 is a representative section of these maps for DO in Raritan Bay, Kill van Kull and Arthur Kill. The complete DO estuarial map also includes the Hudson River to Bear Mountain, the East River, Western Long Island Sound and Jamaica Bay. Maps of the other parameters also have been prepared; their areal coverages reflect the availability of the data. These maps are available at cost from the authors.

and at New Brunswick on the Raritan River would affect the western end of Raritan Bay within 12 to 18 hours respectively. These findings dispute the view that most of the effluents dumped into Arthur Kill drain through Kill van Kull and the Narrows rather than through Arthur Kill. Short-term preliminary analysis of the water quality, based on data collected by the Interstate Sanitation Commission covering short periods of a few weeks, do support the Kill van Kull-Narrows hypothesis. The discrepancies appear to be caused by differences in the sampling period and duration of the Walker and ISC studies. When the data are viewed in a spatially and temporally wider context, however, it appears that both the extreme eastern and western portions of the Bay are affected detrimentally by the water which drains into the Bay from the three major water sources.

The geographic patterns revealed by the supplemental maps not included in this report owing to space and cost limitations are summarized as follows:

(1) The estuary exhibits increased DO values as the distance from the central part of the harbor increases. Except for a small area immediately south of Peekskill the increase in DO is particularly marked on the Hudson, reflecting the lighter population densities in Putnam and Westchester Counties and the smaller effluent outflow per unit area. An increase in DO value is also evident on Long Island Sound toward the east, except for some of the bays which may reflect lower rates of reoxygenation, caused by the reduced flushing effect to which these bays are subjected because of urbanization.

(2) The pH maps verify the water inflow to the Raritan Bay as previously discussed. These values are generally low for the central portion of the estuary, Upper New York Bay, Newark Bay, and the Kills, reflecting somewhat higher acidic conditions. The pH pattern in Long Island Sound is somewhat more complex, probably influenced by complex currents combined with acidic effluents, possibly originating from several points.

(3) Nitrate, phosphate, and streptococci are less well represented and are skewed in the direction of lower values. Although showing less variation from area to area than the other parameters, they do exhibit slightly higher concentrations in the central portion of the study area, with declining readings toward the periphery.

(4) Phenols had already been discarded for mapping purposes, since it was only represented in the west-central portion of the study area. Consequently, there was insufficient information concerning the distribution of phenols in the remainder of the estuary.

C. Evaluation

On the basis of our analyses and reviews of the many isolated surveys conducted in various parts of the estuary, we believe that a consolidation of the monitoring efforts of the agencies which have interests in the estuary should be made. Effective coordination would result in a more uniform coverage of the surveillance of the water quality as well as eliminating the inefficiences that result from duplication. It is recommended also that research be conducted to verify the relationship between water quality, monitoring methods, and the uses -- actual as well as potential -- of the estuary.

CHAPTER V

REVIEW OF THE SIGNIFICANCE OF THE DATA BASE ANALYSIS

A large mass of data on the waters of the New York-New Jersey Metropolitan Region has been assembled and screened in Chapters I through IV. How useful are these data for: (1) daily operations of water plants and daily use of water bodies, and, (2) for the development of short-term and long-term policy?

As already noted, most of our efforts have been an exercise in futility, productive of few meaningful dividends. It would appear that the surveillance system has been irrelevant to operations, management and planning program. Much field information has been collected irregularly listing poor techniques based on questionable parameters and an inadequate sampling design; methods of analysis have been widely divergent and storage has been haphazard. Of the two utilitarian questions posed in the preceding paragraph, the data have the greatest bearing on the first and least impact on the second, particularly on long-term policy planning. Indeed, the thrust of the following chapters is to extract planning guidelines from the data.

The daily operational utility of the monitoring information reflects the behavior and restricted views of water managers. Their attitudes reflect the conditions of an earlier period when the land use-water use interdependency was less stringent and less agglomerated into large urban areas than at present. It appears that water managers -- both potable water producers and spent water disposers -- do not view water environmentally. Rather, they tend to regard it dichotomously:

The producer asks: "Is there a sufficient quantity of water available at the intake capable of being transformed into potable water that will meet health standards with the available technology?" If there is, the water producer is satisfied.

The disposer asks: "Is there sufficient treatment capacity available at the outfall to process the waste water to a level that will meet effluent standards with the available technology?" If there is, the water disposer is satisfied.

Neither manager is concerned directly with the quality of the water in the natural body. Their views are essentially determined by the pragmatic demands made on them by single-purpose objectives.

The inadequacy of water-quality record keeping is not surprising, then, in view of the fact that the two classes of water managers have been responsible for water policy. Except for quantity, the water body is irrelevant to their operations. Past technology always has demonstrated its capacity of escalating to meet quality standards or flow irregularities.

In the roll call of technologies available for the management of urban area water systems the one that stands out as pivotal for the maintenance of water quality is chlorination. This is seen by widespread influent and effluent chlorination practices and, even, in-stream chlorination.* Until

*New York City chlorinates five streams in Westchester County (Board of Water Supply, 1969).

fairly recently chlorination was a reliable method to transform low-quality water from natural sources into nondisease-transmitting potable water for urban communities. But a new generation of persistent toxic metals and synthetic organics and an awareness of pathogenic viruses which do not respond to treatment by chlorine, now threaten to weaken the unique role of chlorine in the water supply system.

Decreased reliance on chlorination as a panacea shifts the responsibility for the maintenance of water quality in the direction of an enforcement effort, resting on a more effective monitoring system. The temporal, spatial and in-situ design properties of the surveillance net; the selection of sensed parameters; methods of record keeping, information storage and retrieval must be reevaluated. The point of irrelevance between the monitoring of water and the treatment of water has been passed. Accompanying the integration of influent treatment and water sensing is the linkage between them and natural water body standards. Standards will have to consider necessary treatment levels and the ability of monitoring to insure their attainment while taking account also of the assimilative capacity of the water to absorb pollutants and a water body's array of potentially beneficial uses -- including potable water, fishing, bathing or dumping. If the monitoring net is unable to provide the information needed to insure the attainment of desired quality levels, policy goals cannot be satisfied.

Most of the data sets examined in this study gave evidence of a substantial gap between monitoring and use. Outstanding exceptions are Nassau and Suffolk Counties in Long Island, where the hydrologic system compels water managers to think concurrently of water supply and waste disposal. Discharge of sewage through plants with ocean outfalls is responsible for falling water tables and salt water intrusion -- both threats to future supplies and offshore waters. Inland discharge by infiltration through large plants or individual cesspools or septic tanks will maintain water levels but pollute the groundwater. An alternative plan would combine an efficient surveillance system with strategically-dispersed package plants able to remove pollutants.

In New Jersey good monitoring data records have been kept by the private water purveyors and the Passaic Valley Water Commission. Here the situation differs from Long Island in that the potable water producers do not exert direct control over the spent water disposers. It is precisely because of their separation that monitoring must assume a paramount managerial role.

The plan for a statewide rearrangement of New Jersey's sewerage structure into a system of regional plants is the surface water analogue of the Long Island groundwater program. And it is bound to have analogous adverse effects -- disturbing the offshore aquatic ecology, causing large scale interbasin transfers, leading to a one-time use of water and leaving natural assimilative capacities underutilized. A dispersed net of package plants in association with an efficient monitoring system offers a solution in New Jersey, as in Long Island.

The point we wish to make is the obvious one that has been overlooked by water planners, as evidenced by our review of water data collection and analysis in the New York-New Jersey Metropolitan Region: a well designed surveillance system is an integral part of water supply and water disposal in urban areas. Thus far, its role in water management has been substantially neglected.

PART TWO: Towards a Policy-Oriented Statistical Model for Estimating the Probable Future of the Region's Rivers

This section builds on the data of Part One and attempts to devise a model by which the impact of certain policy alternatives upon river systems with respect to waste treatment strategy may be gauged.

Chapter VI addresses the problem of formulating the effect of urban development upon the pollution load introduced into rivers. It is concerned with devising methods suitable for computer application to make such estimates.

Chapter VII describes the mathematical model by which the impact of the effluents simulated as a result of the processes devised in Chapter VI are translated into variations in the dissolved oxygen quality of the stream.

Chapter VIII presents the findings arising from the application of the model. The reader who wishes to skim Chapters VI and VII may get the gist of our findings by reading Chapter VIII.

CHAPTER VI

THE PROJECTION OF URBAN WASTE WATER EFFLUENTS

The preceding chapters were largely devoted to water quality measurements. If a working model is to be developed for planning purposes, however, it is necessary to grasp the following points:

-- What effluents containing what contaminats are introduced into the waters of the region?

-- Where are these effluent sources located?

-- How can the magnitudes of the effluents be estimated?

-- What impact does the effluent have upon the region's water quality?

-- How do the effluents and their contaminants vary in time?

-- What are the intended uses of the receiving waters?

This chapter will attempt to deal with the first three questions. The succeeding chapters will deal with the last ones.

A. The State of Effluent Data in the Region

The region consists of 21 counties containing 481 minor civil divisions. In 1970, 215 public sewage agencies served 14.5 million of the region's 17.5 million population and the vast majority of its 45,000 industrial plants. However, more than 2,000 of the factories constitute in themselves important potential sources of industrial pollution. Moreover, as impervious surfaces -- such as asphalt, roofs, and other manifestations of urbanization -- cover an increasing proportion of the region's 4,700 square miles, the amount of runoff which either courses directly into the waterways, or sluices in through storm or combined sewer systems increases significantly. Like industrial and domestic sewage, the material is not pure. It is contaminated by all kinds of chemical and biological material such as road salt, oil slicks at filling stations, lawn food and fertilizer, animal waste and products of decay from garbage dumps.

Thus, at the very least, some estimate must be obtained related to the threefold categories of domestic sewage industrial effluent and runoff. Unfortunately, the data in these vital areas of concern are lacking and -- at least at present -- unobtainable.

In the case of sewage effluent from public sewerage agencies, an examination of the monthly reports that they are required to turn in to the state indicated that those data were -- on the whole -- virtually useless. Fortunately, average yearly figures were available which provided us with some guidance.

With respect to the question of industrial effluent, we endeavored to circulate and follow up a questionnaire to the major regional factories which were unserved by public sewerage treatment plants. This undertaking proved to be a complete failure. Even after strenuous efforts, only seven percent of the sample was returned, and an even smaller number of these was usable.

The contribution of runoff is likewise little studied and poorly understood. The literature focuses on peak flows -- and resulting flood potential -- and the impact of suburbanization in previously undeveloped areas, with generally more emphasis on considerations of flood control than water quality. (Leopold, 1968; Seaburn, 1969; D. Anderson, 1968; P. Anderson and S. Faust, 1965; Guy and Ferguson, 1962.) We found all research on urban runoff inapplicable to the solution of our empirical field problem. (American Public Works Assn., 1969; Economic Systems Corp., 1970). In any event it was well beyond our resources to do the detailed field work suggested by these reports. In this situation, we had to devise indirect methods for estimating the magnitudes of these components of pollution: the public components; the runoff component; the industrial component.

1. The Public Component

The major regional considerations likely to influence the public component are presented in Table 1. They are partitioned into two columns which separate those factors tending to produce major increments in pollution from those tending to produce more minor increments.

Table 1. Key Considerations for Analyzing the Public Effluent Module

HIGH POLLUTION CIRCUMSTANCES	LOW POLLUTION CIRCUMSTANCES
1. region's population increases and remains in densely developed areas (older, leaky combined systems)	1. region's population stabilizes
2. increased share of the region's population is served by sewerage systems	2. share of population served by sewerage systems stabilizes or decreases
3. retrogression or no improvement occurs in treatment	3. improvement at least to treatment levels suggested by the government
4. per-capita effluent discharges increase	4. per-capita discharges stabilize or decrease
5. combined sewerage systems are maintained	5. combined systems are replaced by separate sewers
6. more industries turn to public systems, especially systems with inadequate treatment	6. industries refrain from the use of public facilities, and public systems turn to industrial treatment facilities
7. construction of a few large treatment plants replaces older dispersed plants	7. dispersal of many treatment plants of high efficiency

One is immediately struck by the fact that the question of population increase is crucial to many aspects of this table. In fact, it is clearly necessary to estimate population change for the service areas of all the public agencies in order to devise coefficients which will transform this population change into estimated influent contributions. In order to accomplish this task, we devised the population projection model which is discussed in detail in Appendix 1.

The results of the projection, however, clearly suggest that the high pollution set of circumstances is most likely to prevail. The region's population is likely to increase from 17.5 to 21.5 million between 1970 and 1985. The increase should occur despite both recent marked decreases in human fertility ratios and the probability that the New York region will become a net exporter of population by 1985. The internal redistribution of population and associated commercial activity from densely developed to sparsely settled areas should increase. However, the movement is likely to be dramatically reduced through the period of inflation, and slowed, especially in the suburbs, due to a legacy of restrictive zoning ordinances. Summarizing, the concentration of population in areas served by presently inadequate treatment systems is likely to continue in the near future. These high pollution circumstances are now discussed in detail.

a. Degree of Sewerage Service

Eighty-three percent of the New York region's population was served by sewerage systems in 1970. Another 11 percent should have been. Public systems should serve an increasing share of metropolitan populations by 1983, for some of the following reasons. Septic tanks, cesspools and other forms of private disposal have repeatedly been found ineffective. They have often resulted in polluted water supplies and the prohibition of swimming. Many present and expected suburbanites are former city residents who are used to public sewerage and water service and are not inclined to deal with septic tanks. Finally, sewers are much cheaper to install at the time of development construction.*

The tendency to plan for sewers at population densities below presently recommended Federal levels (5,000 per square mile necessary) was apparent in the 41 county reports. Sewerage systems were advocated for communities with planned densities above 2,500. Indeed sewers were strongly recommended

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*Suffolk County, New York is a classic case of the aftermath of failing to install sewers at the time of construction. Suffolk's population grew from 276,000 in 1950 to 1.1 million in 1970. Cesspools (more than 250,000) and water supplies from individual wells were permitted. The results are now being faced. Disposal of effluents into the ground has polluted many wells. Detergents have been banned. Flynn estimates the cost of installing sewers in already settled areas of Suffolk as three times the cost of installing them during construction. The individual county resident who was originally permitted to settle without a wastewater system is expected to have to pay tax increases of 18 to 26 percent for its belated installation. (John M. Flynn, 1968.)

in areas with expected densities of 1,500 when these areas were characterized by soil and bedrock conditions unfavorable to private disposal. Overall, the share of the New York region's population served by sewerage systems should rise from 83 percent in 1970 to about 92 percent in 1985.

b. Treatment of Influents

The Federal Water Quality Act of 1965 aimed at drastically reducing water pollution by 1973 (United States Code, 1970). The New York region might approach the federal standards by the late seventies, but more likely by 1980. Presently, 45 percent of wastewaters receive only mechanical treatment (primary) or no treatment whatsoever. More than a dozen major treatment plants (capacities greater than a million gallons a day) are receiving average flows that exceed their capacities. (Author's tabulation)

After speaking with local officials and reading county master plans, the authors concluded that only a few of the present deficiencies would be corrected by 1975. Accordingly lower pollutional loadings were inserted into the public module beginning in 1975, with increasing impact in 1980 and 1985. If present treatment levels are upgraded to the levels suggested in county master plans, we estimate that by 1985 the amount of oxygen-demanding wastes released by public systems should be reduced to one-third of present levels (see Table 2 for details).

Table 2. Summary Data for Public Effluent Module: 1970 and 1985 Plants Receiving at Least 0.1 Million Gallons Per Day

Area	Number of Plants[a] 1970	1985 A	1985 B	Flow 1970 millions of gallons per day	Flow 1985 millions of gallons per day	BOD[b] 1970 millions of pounds per day	BOD[b] 1985 millions of pounds per day
Northeastern New Jersey[c]	117	120	52	647.2	1018.2	1.129	.212
Other New York State and Connecticut[d]	84	110	55	322.8	569.2	.203	.108
New York City	14	14	14	1397.0[e]	1718.9	.706[e]	.358
TOTAL	215	244	121	2367.0	3306.3	2.038	.678

[a] The letters "A" and "B" refer to two alternative strategies for dealing with regional wastes. Strategy A contemplates the preservation and upgrading of existing plants. Strategy B contemplates phasing out small plants and building a lesser number of large, modern facilities in their place.

[b] 5-day biochemical oxygen demand, a common measurement for human wastes.

[c] Includes the following counties: Bergen, Essex, Hudson, part of Mercer, Middlesex, Monmouth, Morris, Passaic, Somerset and Union.

[d] Includes the following counties: Fairfield county, Connecticut; Nassau, Rockland, western Suffolk, and Westchester County, New York.

[e] Includes an estimate of untreated flows not passing through treatment plants.

c. Per-Capita Discharges

Although the usual data problems obscure a clear trend in per-capita effluent discharges, it nevertheless appears probable that in the New York region per-capita discharges of human wastes should not appreciably change, except in subregions which manifest the following characteristics strongly: ordinances which permit garbage grinders, a growing population of single-family dwellings, the likelihood of substantially increasing water rates, the likelihood that metering will be extended to unmetered areas and the likelihood that combined sewerage systems will be converted to separated systems.

d. Combined and Separated Systems

Forty percent of the national population residing in areas that are served by sewerage systems are served by combined systems (American Public Works Association, 1967). The comparable datum for the New York region is 80 percent. Accordingly, the New York region is especially susceptible to discharges of untreated wastes following heavy precipitation. (Author's tabulation.)

Little change in the present pattern is expected. While it can be assumed that all new developments will receive separated systems, nearly all areas with combined systems are likely to retain them. Separation is clearly preferable. However, the expensive technical difficulties likely to result from attempting to replace water mains in a maze of water, sewer, electric, gas and telephone pipes seem destined to deter separation. Thus, only major areas undergoing urban renewal or areas with substantial funding sources are likely to make the change.

e. The Industrial Effluents in Public Sewerage Systems

While per-capita discharges of human wastes and infiltration to public systems are expected to be relatively stable, the industrial use of public systems is likely to increase substantially in the face of mounting pressure to improve water quality. Most industries will turn to the public systems as an alternative to constructing their own treatment facilities. This will doubtless include industries which were formerly excluded from public systems because of the corrosive and toxic nature of their effluents.

The choice of whether or not to use the public system involves thousands of individual managerial decisions. While educated guesses may be made with respect to which industries are likeliest to join, no precise means of determination is available. For our purposes, a list was developed from a variety of reports and compared to the literature. Further research into this question is required.

f. Location and Size of Public Treatment Plants

Federal, state and county reports emphasize the virtues of regionalization. Regionalization is explicit in the Federal Water Quality Act of 1965: (1) the development of comprehensive river basin studies, (2) the encouragement of interstate compacts, (3) the requirement of conformability with basin studies for federal grants, and (4) a 10 percent incremental grant if the plant is part of a metropolitan regional plan (United States Code, 1970).

While the large, regional plant is not explicitly called for in these provisions, regional control and regional plants seem to go together. The guiding principle in treatment plant location appears to be regional control through reduction in the number of plants. The ideal is to locate a single plant at the lowest point in each drainage basin.

As the level of the political unit decreases, the tendency to favor regionalization decreases. Yet as far down as the county level the vast majority of decision-makers favor the regional system. Seventeen of the 21 counties in the NYMR have adopted or are likely to adopt regionalization plans. The most obvious impact of these plans would be the reduction in the number of operating treatment plants. As Table 2 indicates, the impact of strategy "B" is quite variable -- from more than a 50 percent reduction in the number of plants in northeastern New Jersey to no change in New York City.

As pointed out in Chapter V, the location and size of wastewater facilities should not be viewed as a simple engineering-economic question. The decision will influence the development of the urban fringe as surely as does the creation of a new highway. The unwise location of wastewater facilities can have deleterious effects on the economic base of the central city. The problem of location is a complicated economic one with conflicting long and short-term effects, and can have a mixed impact on environmental quality goals. Since governmental support programs emphasize aid to capital construction, but not to operation or maintenance, it is clearly less costly to build a few large plants located at the lowest point in the drainage basin, under present policy structures, than to upgrade, maintain and develop numerous smaller plants at a variety of upstream locations. If cost minimization is the chief policy criterion, it can hardly be surprising that the large plant policy has gained wide currency. Yet such a policy may be in direct conflict with an optimization procedure which seeks to minimize adverse ecological impact. In such a case, public policy should shift the reward and support structure so as to encourage the convergence of the least cost solution with the minimum ecological impact solution.

Some advantages of a regional system seem clear. Public water supplies and a number of recreational activities can be enhanced because streams would not receive effluents in extensive upstream stretches. Nontoxic industrial wastes can be diluted by organically poorer domestic wastes. Solid and gaseous disposal problems may be reduced as the number of local dumps and incinerators can be minimized. And sludge reclamation may proceed more economically.

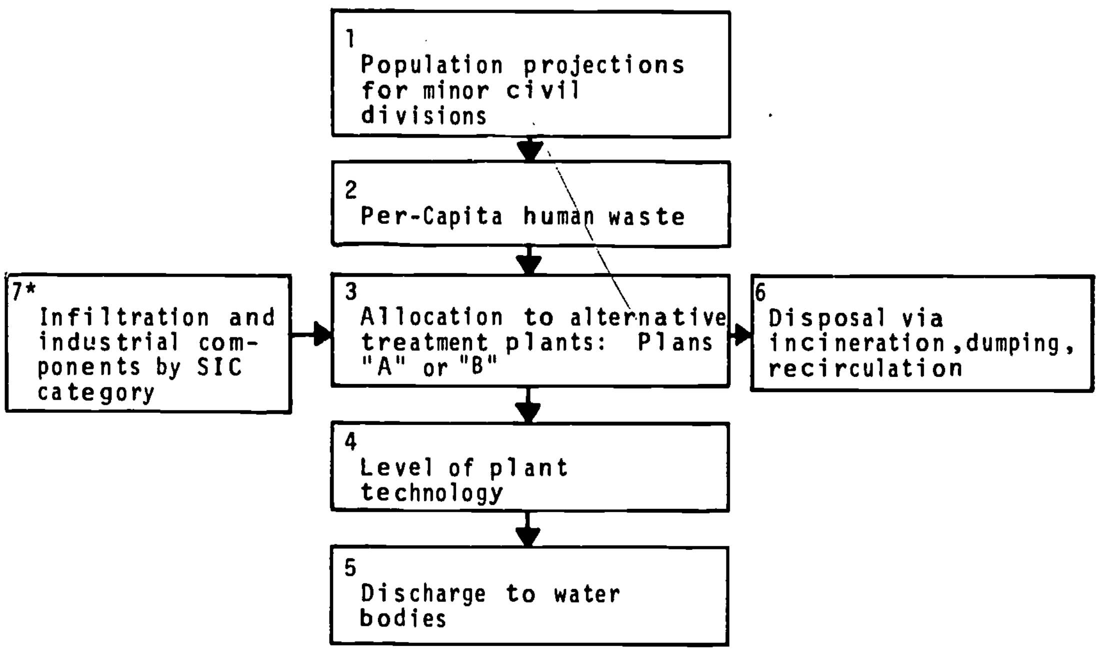
The disadvantages, although less obvious, may be potentially more important. Greater dilution of industrial wastes may be accomplished by larger plants; however, random slugs of toxic or volatile wastes can result in the discharge of dangerous and massive pollution loads. The disastrous effects of mechanical failure are compounded when a single large plant is involved. Larger plants may remove a larger percentage of incoming biodegradable wastes, but if nondegradable, metallic compounds are included as part of their effluent, they may be concentrated in portions of water bodies.

These and related questions have not yet been adequately studied. The regional concept seems already ingrained through inertia in the fabric of public policy as shown by the data on Plan B in Table 2, above.

It will be part of our concern to test some of the implications of these two plans -- Plan A and Plan B -- by means of our model.

Figure 1, below, indicates how public effluent discharge was estimated.

Figure 1. Schematic for the Simulation of Public Effluents



In all, this troublesome Public Effluent Module was required to project 8,400 bits of information to serve as an input to the stream simulation model bearing upon the effect of Public Sewer Authority effluent generation. We now proceed to consider runoff.

2. The Runoff Component

The key factors in estimating runoff pertain to impervious cover and terrain characteristics. We now turn to these relationships.

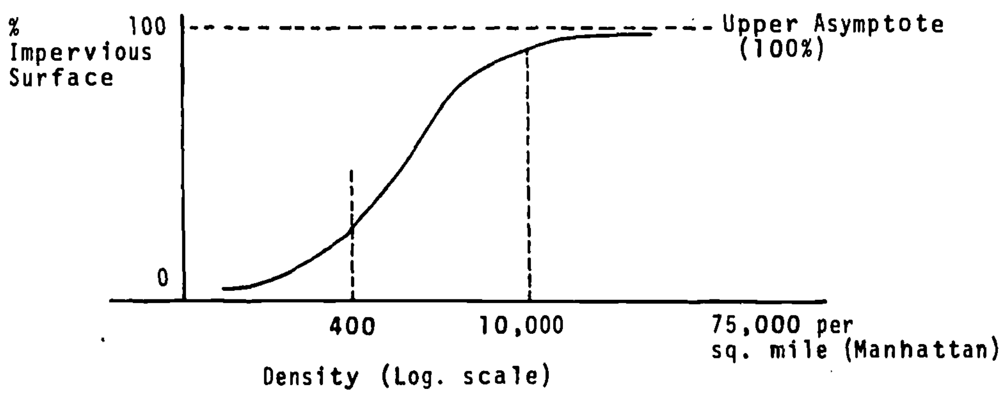
a. Impervious Cover

The percent of the land surface covered by impervious surface is clearly related to population density. At two extremes -- the natural environment

*The information in box 7 -- Infiltration and industrial components by SIC category -- was compiled after a laborious search of the information listed in Appendix 2. The chart of coefficients by four-digit SIC category is reproduced in Appendix 3.

in the absence of man, and an environment such as Manhattan -- the percent of land surface covered by impervious surface are at a minimum and maximum. We theorize that Figure 2 represents the kind of S-shaped growth curve typical of an urbanized region.

Figure 2. The Relationship Between Density and Percent of Impervious Surface



The curve breaks out into three regions related to the density ranges of 0-399, 400-9,999, and 10,000 and beyond. These break-points were observed by actually considering the density - impervious surface characteristics of the minor civil divisions in a portion of our region.

Based on these observations, we fitted the curve in Figure 2 by means of three least-squares linear regressions approximating the function in the three critical regions.

$$_tI_i = 7.75 + .00347\,_tX_i \qquad (0 \leq {}_tX_i \leq 399) \qquad (1)$$

$$_tI_i = 11.33 + .00676\,_tX_i \qquad (400 \leq {}_tX_i \leq 9{,}999) \qquad (2)$$

$$_tI_i = 80.59 + .0000425\,_tX_i \qquad (10{,}000 \leq {}_tX_i) \qquad (3)$$

In these equations, $_tI_i$ represents the percent of impervious surface of the i^{th} minor civil division in time t. The index i ranges from one to 481, and t is 1950, 1960, 1970, 1975, 1980, 1985 respectively. $_tX_i$ represents the density of the i^{th} minor civil division at time t. Notice how -- as we theorized -- the slope parameter is extremely flat in equation 3, while it is steepest in equation 2. This table function approximation fits the real data poorly in two cases: (a) predominantly parkland areas with a few densely developed apartment clusters; and (b) communities with large water bodies. Adjustments can readily be made in these few cases, however.

b. Terrain Characteristics

Also related to runoff are the slope features of terrain plus the hydrological properties of the land and underlying rock. There are two broad terrain regimes of relevance to us in our study area: the coastal plain and the piedmont. We thus state that our best estimator of runoff is a function such as equation 4 below.

$$_tR_i = a + b_1 {}_tI_i + b_2 {}_tD_i \qquad (4)$$

In this function, $_tR_i$ is the runoff from the i^{th} civil division at time t, D_i is the geohydrological dummy which is 0 for coastal plain, 1 for Piedmont. The a and b's are regression coefficients and the indices vary as in equations 1-3. It is in this form -- in Chapter IV -- that runoff is built into the model.

3. The Industrial Component: Effluents Not Included in Public Sewerage Systems

In order to estimate these effluents, we utilized the coefficients as developed in Appendix 3. But it was necessary to estimate the product output of any given plant in order to apply the coefficients. Again, a modified shift-share model was used to estimate production trends in regional localities as compared to national trends. This procedure is given in Appendix 4 in some detail.

Given these estimates, the modeling strategy was easy. By multiplying estimates of production by the effluent coefficients per unit of product, plant effluent estimates are established. These are then partitioned among the following treatment paths: (a) a public sewerage system, (b) private pretreatment and thence to the public sewerage system, (c) completely private treatment or nontreatment with discharge into a waterway.

C. <u>Conclusion</u>

Effects of public sewerage system effluent, industrial effluent and runoff were estimated for incorporation into the model. Basic to the various estimates are three sets of data.

- Projections of population growth,
- Production projections of industrial output,
- Coefficients of domestic sewage and industrial effluent production.

Establishing procedures for estimating these factors adequately -- covered in Appendices 1-4 -- consumed much time. They were absolutely necessary, however, in an environment of spurious data and reluctance by both public and private officials to provide effluent data.

CHAPTER VII

SIMULATING DISSOLVED OXYGEN VARIATION IN AN URBANIZING WATERSHED

It has been customary in engineering practice to calculate the dissolved oxygen level (DO) of a body of water by developing a mass-balance relationship based upon reoxygenation and deoxygenation processes as set forth initially by Streeter and Phelps (1925) and subsequently developed through numerous studies.

Because equations which serve as the structure for this approach involve coefficients of deoxygenation and reoxygenation which are themselves exponential functions of water temperature, the calculations based upon these equations may be very cumbersome. For most engineering purposes, the DO behavior of a stream under the impact of organic pollution (measured in BOD) is sought over a short time period -- 24 or 48 hours, perhaps. To all intents and purposes, it may be assumed that water temperature does not fluctuate much in that period of time, thus the values of the coefficients remain constant. Under these conditions, the calculations of the Streeter-Phelps equations are simplified, since the equation parameters are invariant. (G. M. Fair, J. C. Geyer, D. A. Okun, 1971).

We cannot make this assumption about the simulation of DO over an entire year for a given stream station. We, therefore, required an approach in which estimation calculations would be simple enough to computerize for several dozen stations on a river system simultaneously, preserving mass balance effects wherever untreated or undegraded BOD from upstream is passed on downstream.

Furthermore, as our previous chapters reveal, detailed data on the sewage introduced by various effluents into the stream at each station for each episode of water quality measurement are not available. Due to the inadequacy of effluent data, we have at our disposal only monthly or twice monthly arithmetic means of effluent introduced by treatment facilities over two to three years.

For these reasons, we have cast about for an alternative method of estimation by which to replicate DO in a river system. The results of our inquiry are presented below.

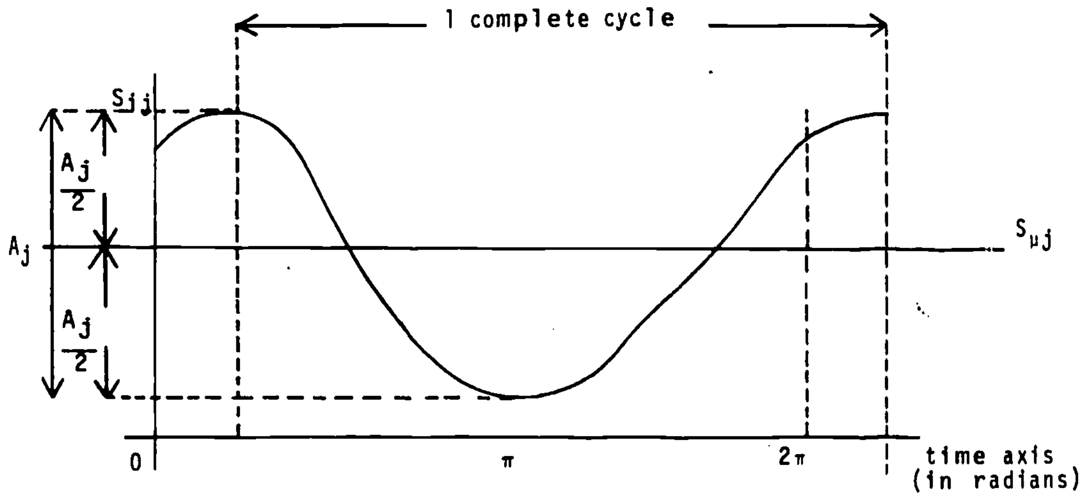
A. Replicating DO in River Systems

In an unpolluted stream, DO is inversely related to water temperature. But because of the astronomical motions of the earth, water temperature is a trigonometric function of time. Thus, following the lead of Thomann (1967), DO may be predicted by means of a harmonic function with time as the independent variable. For the i^{th} observation at the j^{th} station:

$$S_{ij} = S_{\mu j} + A_j \cos(\omega t_i - \theta_j). \qquad (1)$$

S symbolizes DO, t is time, ω is a scale factor which transforms time into radians, θ is a phase angle and A is the amplitude of the curve. $S_{\mu j}$ is the mean value of dissolved oxygen about which the curve oscillates at the j^{th} station.

Figure 1. Graphic Representation of Equation (1)



When pollution is introduced into the stream, the mean dissolved oxygen (S_μ) will be diminished. Thus, we say,

$$S_{\mu j} = \sum_i \alpha_{ij} P_{ij} + \sum_k b_{kj} F_{kj} + \varepsilon \qquad (2)$$

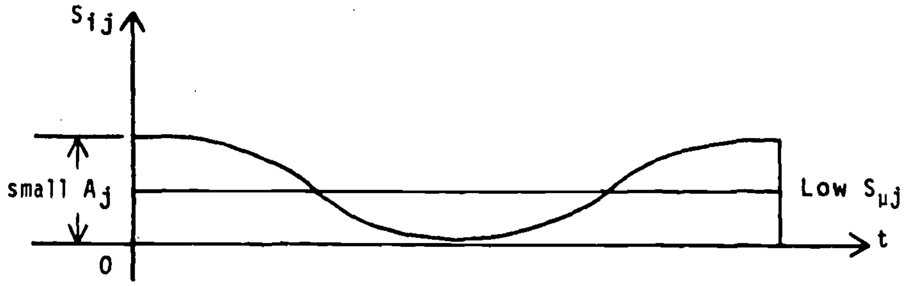
For the j^{th} station of a river system, the mean DO, $S_{\mu j}$ is a function of the mean load of the i pollution variables, P_i and the value of k stream parameters F_k. The α_i and b_k are regression coefficients, and ε is a normal random variate.

But the range over which S_{ij} and $S_{\mu j}$ may vary is not unlimited. Fresh water under standard conditions becomes saturated near 14.6 ppm of DO. And clearly, values of DO may not be negative. Thus the constraint:

$$0 \leq (S_{ij}, S_{\mu j}) \leq 14.6. \qquad (3)$$

This produces an interesting relationship between the two parameters of equation (1), $S_{\mu j}$ and A_j. In a polluted stream, where $S_{\mu j}$ is depressed, the harmonic function will be constrained against the lower horizontal axis, at $S_{ij} = 0$.

Figure 2. Harmonic Function With Low $S_{\mu j}$



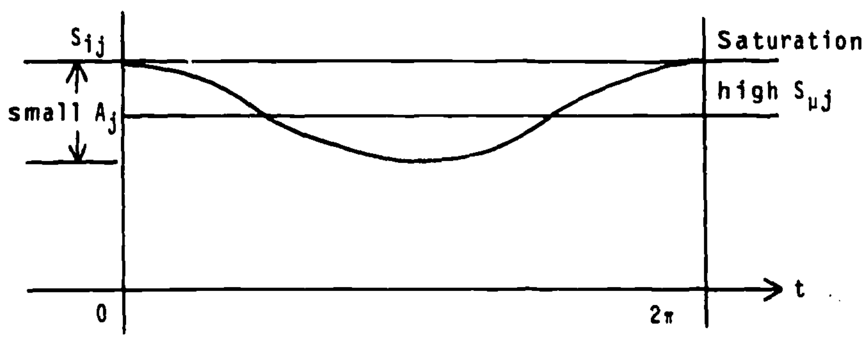
Since the variance of S_{ij} is a function of the amplitude in a harmonic curve,

$$\sigma_j^{\ 2} = \frac{A_j^{\ 2}}{2} , \qquad (4)$$

at the j^{th} station, (Panofsky and Brier, 1968) where $\sigma_j^{\ 2}$ is the variance. Thus, we assert that when $S_{\mu j}$ is low, $\sigma_j^{\ 2}$ will also be low.

Moreover, when values of $S_{\mu j}$ are high, the curve will impinge upon the upper asymptote representing saturation.

Figure 3. Harmonic Function With High $S_{\mu j}$



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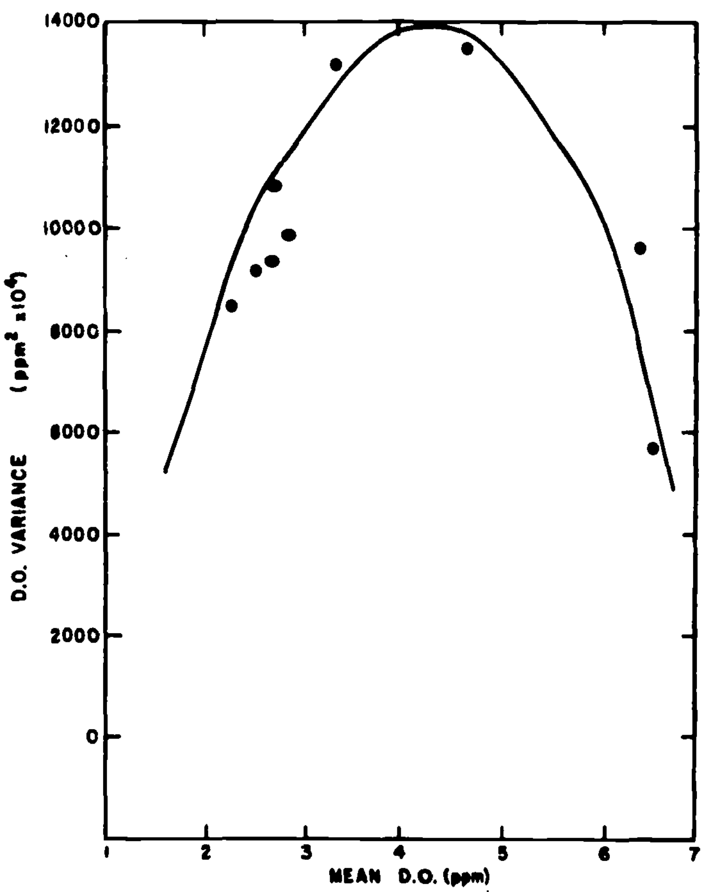
In intermediate ranges of S_{uj}, the A_j will reach a maximum. This situation is well represented in the analysis of Wastler, (1969).

Figure 4. DO Variance as a Function of Mean DO, Potomac Estuary, August, 1959



Accordingly, one might entertain the idea of estimating the amplitude of S_{ij} by means of a curvilinear regression against S_{uj}. In fact, we did not have the data to do this since our stations all demonstrated S_{uj} values which fell on the right-hand branch of the curve -- only a very few were so polluted as to fall on the left-hand branch. We therefore adopted the following approximation, where S_{uj} is mean DO and D_j is a dummy variable applying to points to the left of 7.5 ppm on the S_{uj} scale. This is equivalent to estimating most of the points by means of a straight line approximation, and the left-hand branch points (which were closely clustered) as a group.

$$A_j = b_1 S_{\mu j} + b_2 D_j + \epsilon \qquad (5)$$

By virtue of the fact that rivers are flow systems, and the phase angle, θ, is a parameter which estimates the time when DO reaches a maximum, we hypothesized that for river systems relatively free of impoundments and impediments to flow, the θ at all stations should be similar. The values assumed by θ in Table 1 verify this assumption.

Table 1. Phase Angles on the Raritan System

Station	θ	Station	θ	Station	θ	Station	θ
0154	6.0	0175	5.9	0186	5.9	0170	5.7
0155	5.9	0176	5.9	0187	5.9	0171	5.7
0162	5.8	0177	5.9	0188	5.8	0182	5.8
0165	5.8	0178	5.8	0164	5.8	0183	5.8
0168	5.8	0179	6.0	0166	5.8	0185	5.9
0172	6.0	0180	6.1	0167	5.6	Mean	5.8
0174	5.9	0181	5.9	0169	5.6		

Regrouping, these equations form the basis for estimating DO on the river system.

$$S_{ij} = S_{\mu j} + A_j \cos(\omega t_i - \theta_j) \qquad (1)$$

$$S_{\mu j} = \sum_i \alpha_{ij} P_{ij} + \sum_k b_{kj} F_{kj} + \epsilon \qquad (2)$$

$$0 \leq (S_{ij}, S_{\mu j}) \quad 14.6 \qquad (3)$$

$$\sigma_j^2 = \frac{A_j^2}{2} \qquad (4)$$

$$A_j = b_1 S_{\mu j} + b_2 + \epsilon \qquad (5)$$

Knowing the pollution variable and stream parameter inputs in (2) allows us to proceed to (5), under the boundary conditions set forth in (3) and (4). Having estimated the A_j from (5) and the $S_{\mu j}$ from (2), the parameters of (1) are completely specified, since θ may be empirically estimated for the system, and t is dependent on the frequency of observation of the data. We must now indicate how the P_{ij} and F_{kj} which start the simulation are specified.

1. The Independent Pollution and Stream Parameter Variables

The variables relating to the effect of pollution load in the stream on DO are discussed in previous chapters. They include:

- Organic loads from wastewater sources,
- Runoff from land surfaces,
- Reoxygenation from stream turbulence,
- Factors of basin geometry related to flow and current.

Percent of impervious surface was used as a surrogate for runoff (in the manner discussed in an earlier chapter). Reliable average annual BOD values or treatment capacities were obtainable from sewage treatment facilities, while more detailed data from those sources were useless. To address the questions of stream turbulence, and stream geometry related to oxygen sag and reoxygenation, the following parameters were utilized: stream slope, cross-sectional area, and the nature of the underlying geologic formations. A detailed discussion now follows.

a. BOD

This variable enters a given stream segment in one of three ways: discharge of effluent, runoff or downstream flow from the segment next upstream. In our model, all of the stream segments are centered on observation stations and arranged from upstream to downstream. The mean BOD entering into the segment through effluent discharge is stipulated, and the BOD accruing from upstream is added to it according to a table function related to velocity (using slope as a surrogate.)

Those segments furthest downstream have the least channel slope -- but the hydraulic friction is also least, owing to the greater flow efficiency of larger volumes of water. In other words, a decrease in particle size downstream results in a reduction in flow resistance. Consequently, channel roughness decreases slightly downstream, leading to a slight increase in velocity as one goes from upstream to downstream (Leopold, Wolman and Miller, 1964). Upstream segments with steeper slopes often manifest great turbulence, but -- owing to frictional inefficiencies -- the mean velocity is slightly slower. Thus, ironically, steeper slopes imply <u>slower</u> transport of water while gentle slopes imply faster water transport (see Table 1).

Table 2. Table Function of BOD Passed Downstream Under Different Conditions of Slope

Status of Stream Flow	Slope	Percent BOD accumulated at downstream station	Remarks
Fast	$S < 2.5$	100%	BOD transported: no assimilation
Medium	$2.5 < S < 5$	50%	Some BOD assimilated
Slow	$S > 5$	0%	All BOD assimilated

The specific values used in the table function are empirical -- related to our data on the Raritan and the Passaic Rivers. Yet, as we shall indicate in the next section, when we reran our model with many systematic table parameter changes for the purpose of evaluating the sensitivity of the model to specific parameter values, we found that the model was not sensitive to the table values.

These were the steps followed in inserting BOD into the model.

(1) Read in the mean BOD contributed to the j^{th} segment by effluent discharge from treatment plants.

(2) Add to it BOD contributed from the $(j - 1)^{th}$ segment by stream flow.

(3) Divide the result by the cross-sectional area of the stream (to express it in terms of concentration).

(4) Take the logarithm of that BOD concentration (empirically the best fit).

b. Turbulence

The longitudinal profile of a stream tends to a logarithmic slope in which the steeper upstream reaches manifest greater turbulence than the more hydraulically efficient downstream reaches. Thus the logarithm of slope was used as a surrogate for this variable.

c. Geologic Formations

Two structural regions form the basis for our Raritan area of simulation. This was expressed by a dummy variable which assumed a value of 0 for the upland region, and 1 for the coastal plain region. On the Passaic, the contrasting regions were swamp vs. upland.

d. Runoff

Impervious surface, as estimated from population density after the manner of Chapter III, was used as a surrogate for runoff plus unmonitored, and bypassed effluents.

Then we derive a relationship based on equation (5) above as follows:

$$S_{\mu j} = 9.542 - 0.634B_j - 5.191I_j + .544\ L_j - 1.155G_j + \varepsilon \qquad (6)$$

B_j is the calculated BOD load at the j^{th} station according to the method outlined above. I is impervious surface (a surrogate for BOD from bypass and runoff), L is slope (a surrogate for turbulence), and G is the geological dummy variable. The equation was calculated for 38 stations in the Raritan watershed by stepwise, least-squares multiple regression.

Once the $S_{\mu j}$ are calculated, the A_j and the S_{ij} may be calculated as well. The S_{ij} form a matrix whose rows represent 26 bi-weekly observation dates, and whose columns represent stations. This is reflected in Table 3.

Table 3. Schematic Representation of the Dissolved Oxygen Simulation Output

	Station 1	Station 2	Station 3	...	Station 38
Jan. 1 Jan. 15 Feb. 1 Feb. 15 . . . Dec. 15		S I M U L	A T E D D	A T A	

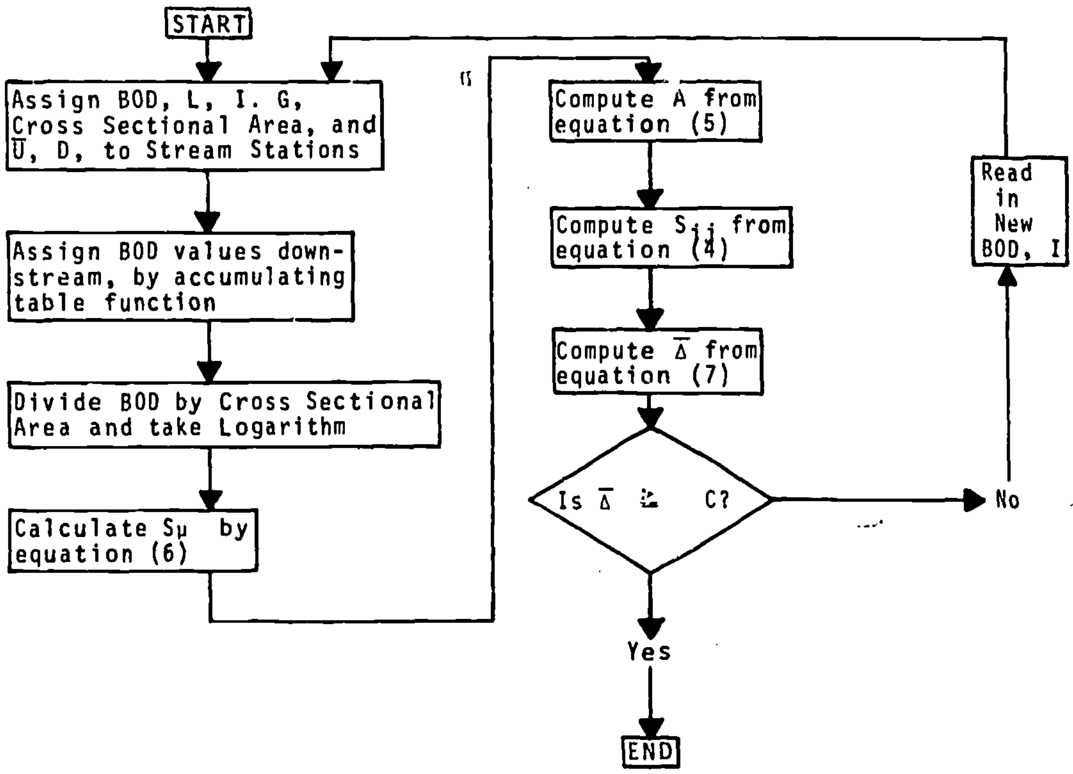
We also prepared a stream standard goal matrix which establishes minimum DO standards for each segment at each time of record. Representing this matrix by U, we find the difference matrix $\bar{\Delta}$.

$$\bar{\Delta} = \bar{U} - \bar{S} \qquad (7)$$

Every entry of negative sign in $\bar{\Delta}$ indicates a failure of a segment at a given time to meet the policy goal. When such entries materialize, we go back to the start, and adjust inputs by tightening up on effluent control and urbanization policy -- which bears upon runoff -- (through operations on variables B and I in equation (6) until we produce a nonnegative $\bar{\Delta}$. The chart in Figure 5 summarizes the procedure.

The model has been calibrated and fitted to both the Raritan and Passaic River system, with equally good results. The Raritan system's rich output, owing to the availability of excellent Federal Environmental Protection Agency data, has prompted us to choose it as the type case for the next section.

Figure 5. Flow Chart of Dissolved Oxygen Simulation



2. Calibration of the Model on the Raritan System

The map of the Raritan presented in Chapter I indicates the location of the 38 sampling stations maintained by the Federal Environmental Protection Agency as well as certain others, such as those of the Elizabethtown Water Company.

a. Empirical Validation

For these 38 stations, we calibrated the model by the procedure outlined above, and then we backfitted our simulated data to the known data from a past year of record (1969-1970) with results as shown in Tables 4 and 5.

Table 4. Validation of Raritan Simulation Model: Correlation Analysis

R^2	Number of Stations
greater than .90	9
.85 - .900	15
.80 - .849	8
.75 - .799	3
.70 - .749	2
.60 - .699	1
TOTAL	38

Table 5. Validation of Raritan Simulation Model: Standard Error of Estimate

Standard Error of Estimate, ppm.	Number of Stations
.50 - .749	5
.75 - .999	14
1.00 - 1.249	13
1.25 - 1.499	4
1.50 - 1.999	2*
TOTAL	38

*Stations 0156 and 0157, both with covariation and constant errors significantly higher than the remainder of the stations. These stations are near New Brunswick.

Thirty-two stations (84 percent of all stations) had a value of R^2 in excess of .80 -- corresponding to correlation coefficients in excess of .90. These results seem excellent, considering the data deficiencies which we have had to overcome. Moreover, of the remaining six stations, only one manifested an R^2 below .70, corresponding to a correlation coefficient between .82 and .78 -- usually considered quite respectable.

The data on standard error of estimate is even more encouraging. Only two stations revealed a standard error above 1.5 ppm, and even these fell within the 2.0 ppm range. Half of the stations had a standard error below 1 ppm.

Furthermore, by examining the data themselves, we can point out that our model tended to err -- small though those errors were -- on the side of conservativism. In other words the simulated DO readings tended to be slightly above the actual DO readings. Thus, if a stream segment fails to meet standards on the simulated data, we have grounds to suspect that the situation in respect to actual conditions is, if anything, slightly worse. In only two stations, 0156 and 0157 is the reverse true -- but existing data shows that these two are already known to be highly polluted.

We are confident that:

- Our model is a simulator well within reasonable bounds of accuracy.

- Our model tends to be conservative. If anything it underestimates the pollution effect.

3. Sensitivity Analysis of Assimilation vs. Transportation Table Function

The table functions by which BOD is adjusted contain various thresholds of slope which determine the extent to which pollution is assimilated or transported to the next segment. These functions fill the role of surrogate estimators for rates of oxygenation and reoxygenation, since they determine the DO-BOD, mass balance relationships in the stream from segment to segment.

To ensure that the threshold levels of these functions did not unduly affect the model, sensitivity runs were undertaken. For the three slope classes utilized, the assumption was initially made that for class I slopes ($\leq$2.5 feet per mile) all of the BOD in the segment would be transported, while for the class II condition (2.5 $\leq$ Slope $<$ 5.0) 50% of the BOD would be transported (and 50% assimilated) and for the class III condition (slope $\leq$ 5.0) none would be transported (all assimilated). The three percentages relating to transportation or assimilation were allowed to vary with the results shown in Table 6.

Table 6. Test of Table Function Parameters for Oxygenation and Deoxygenation Rates

Slope Class I	II	III	Number of Stations Meeting Standards Through 1985	Number of Stations Not Meeting Standards Through 1985
1.0	0.5	0.0	17	21
0.8	0.3	0.0	18	20
0.6	0.1	0.0	19	19
0.3	0.01	0.0	21	17
0.2	0.01	0.0	25	13
0.1	0.01	0.0	27	11
0.01	0.01	0.0	31	7

The table shows the effect of changing the Table Function parameters under present conditions of treatment level technology upon the number of stations which will meet or not meet state standards of 4 ppm minimum DO according to model projections through 1985. The results clearly indicate the insensitivity of the Raritan stations to changes in these parameters. Specifically a change in the parameters from (1.0, 0.5, 0.0) to (0.6, 0.1, 0.0) -- shifting the class I and II parameters downwards by 40% and 80% respectively -- results in only two stations changing from the non-complying to the complying columns. Even if the coefficients are dropped to the absurd values of (0.3, 0.01, and 0.0) -- where virtually all BOD is assimilated and none transported -- only two additional stations change state. Even if we assume that the effects of stream transportation are made effectively zero (0.01, 0.01.0.0) there are seven noncomplying stations remaining under truly fantastic assumptions concerning assimilative capacities.

Thus, while we concede that the Table Function parameters are arrived at empirically, we contend that our policy findings are not importantly connected with their calibration. They can vary rather widely from our assumptions without affecting the model.

B. Summary and Conclusion

A model was developed for simulating the observed DO levels on a river system for a number of observation points and with a simulated frequency of 24 equally spaced observations per year. This model was fitted to 38 stations on the Raritan system, and the simulated data compared well with the actual data when the two sets were backfitted.

The independent variables were (a) BOD from upstream sources and wastewater effluent, (b) BOD from runoff from urbanized impervious surfaces, (c) Turbulence as measured by slope, and (d) Geological formations underlying the river basin.

BOD from upstream sources was estimated by means of Table Functions which were empirically estimated. Sensitivity analysis revealed that these estimates were not critical to the functioning of the model.

In the next chapter we shall use the model to project the effect upon stream quality for the Raritan river system through 1985 in the event of the following:

- Advanced treatment levels are adopted

- The region develops a treatment plan strategy based on a continuation of the present condition of numerous small plants (Plan A of Chapter III).

- The region discontinues small plants and concentrates treatment in a few large plants (Plan B of Chapter III).

- A strategy of limiting urbanization is adopted in order to curtail pollution.

These experiments will lead us to speculate on the relationships among the urbanization, water pollution and public policy in the region.

CHAPTER VIII

USING A STATISTICAL MODEL OF DISSOLVED OXYGEN AS A TOOL FOR EXPLORING POLLUTION POLICY ISSUES

The calibrated model as set forth and tested on the Raritan watershed data was run under a variety of assumptions regarding urbanization, pollution and sewerage plant development for three projection periods through 1985. First, let us explore the results obtained through comparing three possible plans for treating public sewage in the Raritan system.

A. A Comparison of the Impact of Three Sewage Treatment Strategies on the Raritan

The three strategies set forth in Table 2, below, are termed status quo, decentralized and centralized strategies.

The first strategy implies a continuing reliance on the present pattern of small treatment plants supplying present levels of treatment (some provide only primary treatment). This, in effect, continues the status quo.

The decentralized strategy implies a continuation of small plants, but with the difference that secondary treatment is provided (Plan A).

The centralized strategy is the one which most engineering studies favor -- large-scale treatment plants with secondary treatment of all effluents: a centralized approach (Plan B).

In each case, the 1975 and 1980 and 1985 performance of the system is indicated by DO surplus or deficit figure. This figure is obtained by taking the sum of the values by which the minimum permitted DO value of 4 parts per million (in line with state policy) is exceeded or missed during the six critical summer readings. Thus, for example, for the decentralized plan at station 0159 in 1975, we have the following summer projections:

Table 1. Calculation of Summer DO Balance for Station 0159 for Projected 1975 under the Decentralized Strategy

Station 0159	DO(ppm)	DO Balance (DO-4 ppm)	Note
Jun. 1, 1975	4.7	+.7	This is a tidal station near New Brunswick which receives much bypass, runoff and upstream pollution.
Jun. 15, 1975	4.1	+.1	
July 1, 1975	3.8	-.2	
July 15, 1975	3.6	-.4	
Aug. 1, 1975	3.8	-.2	
Aug. 15, 1975	4.1	+.1	

+0.9 - .8 = +0.1 (Summer DO balance)

The higher the summer DO balance is, the better the status of the stream. The lower the DO balance becomes (entering negative numbers on occasion), the more serious the state of the stream. Table 2 reports the balances for every station under the three options projected for three periods.

At first glance it is evident that, whatever option is chosen, the benefit accruing from it will be eroded if regional growth assumptions are correct. For instance, at South River (station 0172) the present trend is for DO deficits to intensify from -10.2 ppm. to -13.4 ppm. If the South River facilities are connected to the Middlesex regional plant (as they will be under the centralized plan) we project an oxygen surplus effect of +7.6 ppm by 1975. But even this will erode to only +4.9 by 1985 if growth trends continue as they are likely to do.

A second look at the table discloses many relatively less polluted minor tributaries -- such as station 0166 -- which do not receive treatment plant effluent either directly or indirectly. These stations benefit from neither the decentralized nor centralized plans. What are the beneficiaries of each plan?

The plan to centralize involves installing a major modern facility at Princeton whose effluent will be inserted into the Millstone tributary of the Raritan upstream from station 0181. This will replace older facilities upstream. It is clear that stations 0182, 0185, 0186 and 0187 will be the principal beneficiaries. The projected benefit to Lake Carnegie in Princeton (station 0182) is particularly notable. The level of surplus under the status quo is projected as ranging from 10.9 ppm in 1975 to 7.3 in 1985. Under centralization it will range from 21.9 to 20.1, according to our estimate.

But the impact will be felt on the more densely inhabited reaches of Millstone downstream from Princeton. At stations 0174, 0716, 0177, 0179, 0181 deficits were projected for 1975 even under the status quo. The centralized plan for the Princeton plant will make an already marginal situation in this area worse, according to our projections. For several of these stations, even the status quo would be better. In sum, we argue that the centralization strategy expressed in the Princeton plant's development will improve water quality somewhat in the more thinly settled upstream reaches of the Millstone at the expense of exacerbating an already marginal pollution situation in the downstream reaches which are not thickly settled, but which are used for public water supply purposes in the areas served by the Elizabethtown Water Company.

The Decentralized Plan

In contrast the decentralized policy of upgrading all existing plants to secondary treatment levels would benefit the lower Millstone stations without adversely affecting the stations upstream from Princeton, according to our model.

These findings lead us to question the reflex acceptance of sewerage system centralization which seems at present to prevail among public policy makers.

Table 2. Summer DO Balances for Stations on the Raritan for 1975, 1980, and 1985 Under Three Treatment Plant Strategies (ppm.).

	Strategy									
	Status Quo			Decentralized			Centralized			
Station	'75	'80	'85	'75	'80	'85	'75	'80	'85	Remarks
0150	- 4.7	- 5.9	- 6.8	- 3.4	- 4.1	- 5.3	- 3.1	- 4.1	- 4.8	Tidal
0151	- 7.2	- 8.2	- 9.2	- 5.8	- 6.8	- 7.7	- 5.3	- 6.4	- 7.4	"
0152	- 4.8	- 7.2	- 8.8	- 3.5	- 5.8	- 7.1	- 2.9	- 5.3	- 6.8	"
0153	-10.9	-13.2	-15.1	- 9.2	-11.6	-13.8	- 9.1	-11.4	-13.2	"
0154	- 9.3	-11.6	-14.0	- 7.9	-10.2	-12.6	- 7.4	- 9.8	-12.2	"
0155	- 8.5	-10.2	-11.6	- 6.7	- 8.6	-10.2	- 6.7	- 8.5	- 9.7	"
0156	-14.2	-15.1	-16.2	-12.6	-13.6	-14.5	-12.2	-13.2	-14.2	"
0157	-17.1	-17.1	-17.7	-15.6	-15.7	-16.3	-15.1	-15.3	-15.7	"
0158	9.6	9.6	7.3	9.6	9.6	7.3	9.6	9.6	7.3	Minor Trib.-No Pub. Eff.
0159	- 1.4	- 3.7	- 4.9	+ .1	- 2.3	- 3.2	+ .4	- 1.9	- 2.9	Tidal
0160	4.3	2.0	1.0	6.0	3.6	2.6	6.1	4.0	3.0	"
0161	6.7	4.4	3.4	8.5	6.1	4.9	8.5	6.2	5.5	"
0162	3.4	1.0	.1	4.9	2.6	1.6	5.2	2.8	2.0	Major Industrial Effluent
0163	16.0	16.0	14.6	16.0	16.0	14.6	16.0	16.0	14.6	Minor Trib.-No Pub. Eff.
0164	- 2.6	- 4.9	- 6.1	- 1.1	- 3.5	- 4.3	- .8	- 3.1	- 4.1	Major Industrial Effluent
0165	9.1	6.7	6.0	9.1	6.7	6.0	9.1	6.7	6.0	Minor Trib.-No. Pub. Eff.
0166	20.1	17.8	16.8	20.1	17.8	16.8	20.1	17.8	16.8	" " " " "
0167	7.9	6.3	4.8	7.9	6.3	4.8	7.3	5.5	3.7	
0168	13.6	11.5	10.3	14.0	12.1	10.3	14.0	12.1	10.3	
0169	15.6	13.9	12.6	16.2	14.4	13.0	16.2	14.4	13.0	
0170	18.0	16.8	16.0	18.0	16.8	16.0	18.0	16.8	16.0	Minor Trib.-No Pub. Eff.
0171	15.2	13.6	12.1	16.0	14.4	12.6	16.0	14.4	12.6	
0172	-10.2	-12.0	-13.4	- 8.5	-10.2	-11.6	+ 7.6	+ 6.1	+ 4.9	South River
0173	- 5.3	- 7.3	- 9.0	- 3.7	- 5.1	- 7.4	+ 7.9	+ 6.7	+ 5.5	" "
0174	- 4.3	- 5.5	- 6.7	- 4.1	- 5.3	- 6.4	- 6.7	- 8.0	- 9.7	Bad Effect of Centralization
0175	10.0	9.1	7.9	10.0	9.1	7.9	10.0	9.1	7.9	Minor Trib.-No Pub. Eff.
0176	- 2.5	- 4.1	- 5.5	- 2.2	- 3.7	- 5.5	- 4.9	- 6.7	- 8.8	Bad Effect of Centralization
0177	- 1.1	- 2.8	- 4.0	- .9	- 2.5	- 3.7	- 3.5	- 5.5	- 7.3	" " " "
0178	22.7	22.3	21.3	22.7	22.3	21.3	22.7	22.3	21.3	Minor Trib.-No Pub. Eff.
0179	- 3.1	- 4.7	- 5.9	- 2.9	- 4.3	- 5.5	- 5.5	- 7.3	- 9.1	Bad Effect of Centralization
0180	15.6	14.8	14.4	15.6	14.8	14.4	15.6	14.8	14.4	Minor Trib.-No Pub. Eff.

Table 2. Continued

Station	Status Quo '75	Status Quo '80	Status Quo '85	Decentralized '75	Decentralized '80	Decentralized '85	Centralized '75	Centralized '80	Centralized '85	Remarks
0181	- 2.9	- 4.3	- 5.5	- 2.5	- 4.3	- 5.5	- 5.3	- 7.3	- 9.0	Bad Effect of Centralization
0182	10.9	9.1	7.3	10.9	9.1	7.3	21.9	21.1	20.1	Benefit from Centralization
0185	- 3.1	- 5.3	- 6.8	- .7	- 2.8	- 4.3	10.9	9.7	8.5	" " "
0186	5.6	4.0	2.8	5.6	4.0	2.8	14.4	13.2	12.1	" " "
0187	2.5	1.0	- .1	2.5	1.0	- .1	13.8	12.7	12.0	" " "
0188	13.0	11.5	10.8	13.0	11.5	10.8	13.0	11.5	10.8	No Pub. Eff.
0189	23.7	21.9	21.6	23.7	21.9	21.6	23.7	21.9	21.6	

The impact of a major quantity of industrial effluent upon the stream may be gauged by glancing at the figures for the stations in the vicinity of 0164 and 0162. The quality of water immediately upstream from these stations -- at 0167 -- shows a strong oxygen summer surplus. At 0164 it becomes a deficit as the deoxygenation effect of the introduced industrial effluent makes itself felt. At 0162 the assimilative capacity of the Raritan -- which is a very sizeable river at that point -- has made itself felt and again a small net surplus is shown, albeit much less than at the upstream point.

Notice also the impact of the polluted Millstone on the less polluted Raritan. Station 0167 is just below the confluence. Upstream on the Raritan is 0168 and on the Millstone is 0174. The 1975 projection under the status quo for these stations shows Raritan water at a surplus of 13.6 ppm mingled with Millstone water at -4.3. The impact is to drop the Raritan water to 7.9 ppm. Then the further impact of the industrial effluent is felt.

Under the centralized Princeton plant plan, the projected impact at the confluence is somewhat worse -- 7.3 ppm in 1975. Again we comment that there are public water supply intakes near the confluence.

All major stations below 0162 are tidal in nature, and most of them are highly polluted. With respect to these stations the difference between the two strategies is very small. No projections indicate the hope that these tidal stations will be brought into a satisfactory dissolved oxygen situation under any of the three strategies.

In this section we have examined the projected impact of three treatment plant strategies on our model. In the next section we will consider the impact of urbanization through bypass effluent and runoff in the model from a policy viewpoint.

B. Urbanization, Runoff and Pollution Impact

In the second series of runs, levels of technology and treatment were hypothetically upgraded for all water treatment plants, and for industrial effluent. Unchanged, however, was the behavior of the variable which estimates the effects of urbanization. In equation six of Chapter VI, the reader may recall that I_i measured the combined effects of urbanization in terms of runoff from impervious surfaces and unreported BOD illegally dumped into streams.

With this in mind, we turn to the results of our second run. Even with extraordinarily high effluent standards imposed upon the public sewage treatment plants and industrial effluent, there are still six stations which fail to meet the minimum standard of 4 ppm. While five of these are in the highly polluted tidal region, one (station 0174) is on the lower reaches of the polluted Millstone, where it enters the Raritan. This reveals the impact of the urbanization of the Millstone valley upon water quality. Table 3 reports the status of these affected stations after this run.

Table 3. Projected DO Deficit Midsummer Reading, Six Selected Stations

Station	Status Quo '75	'80	'85	Decentralized '75	'80	'85	Centralized '75	'80	'85	Remarks
0153	-2.2	-2.6	-3.0	- .7	-1.1	-1.4	0.0	- .4	- .7	Tidal Stations
0154	-2.0	-2.4	-2.8	- .4	- .9	-1.3	.3	- .1	- .5	" "
0155	-1.8	-2.1	-2.4	- .3	- .6	- .9	.5	.1	- .1	" "
0156	-2.8	-3.0	-3.1	-1.3	-1.4	-1.6	- .5	- .7	- .8	" "
0157	-3.3	-3.3	-3.4	-1.8	-1.8	-1.9	-1.0	-1.0	-1.1	" "
0174	-1.1	-1.3	-1.5	- .1	- .3	- .4	+ .1	0.0	- .2	Lower Millstone

When we recall that our analysis of the fit of the model in the preceding chapter revealed a tendency to understate pollution we may be assured that even tertiary treatment effluent standards for public sewerage agencies and perfect treatment on the part of the known major industrial effluent sources on the Raritan will not suffice to meet the policy goal of seeking to assure that the mean summer DO level of any reach of the river will not fall below the threshold of 4 ppm.

This is not to say that the river would not be materially improved, for it surely would be. Rather, it is to say that the factors subsumed under the urbanization variable must be modified by policy if the modest goal of 4 ppm is to be met. Effective policy, therefore, must do the following:

a. All industrial effluent illegally introduced into the river must be identified and stopped; and illegal dumping must be rigorously prohibited by an undoubtedly expensive policing activity.

b. In addition economic and demographic growth which results in the production of impervious surfaces and thus increased runoff will have to be strictly curtailed in at least the tidal and possibly the Millstone valley areas of the Raritan.

Both of these policies taken together represent more than a mere arrest of growth in the affected areas. One foresees that there would be a net loss of industry and jobs as a result of rigorous enforcement and a selective freeze on development.

Thus, we conclude, that if the minimal antipollution goal of 4 ppm threshold is really to be met, there must be not only a limitation of growth, but a planned decline in the areas in question.

C. Some Remarks on the Passaic Model

In addition to the Raritan system, we applied the model to the Passaic, with good results. While we have chosen to examine the Raritan case in detail, it is not inappropriate to comment here on the case of the Passaic.

For calibration purposes, we were able to rely upon only 19 stations containing sound data records as compared to 38 on the Raritan. Hence the Passaic case could not be expected to yield as rich results as the Raritan.

Nevertheless, a comparison of the two models indicates that they are comparable in power, although the second is more limited in scope.

Table 4. A Comparison of Estimating Equation Results for the Raritan and Passaic Basins

	Raritan	Passaic
R^2 simulating DO	.74	.79
Standard Error of Estimate (ppm)	0.82	1.04
R^2 simulating C	.82	.82
Standard Error of Estimate (ppm)	.33	.28

Whereas the environmental dummy variable in the Raritan case compared the coastal plain with the piedmont, the appropriate contrast in the Passaic basin was between the Great Swamp area on the upland region above the Passaic Falls, and the balance of the river. Hydrologically speaking, the Great Swamp stations receive unusually high organic discharges arising from plant decay, and the flow characteristics along with the relation of the river to groundwater levels is quite distinct in this area -- in marked contrast to the rest of the river. This Great Swamp dummy variable was highly significant in the model.

The performance of the impervious cover variable differed from the Raritan case. It did not contribute significantly to the Passaic model. The reason for this lies in the fact that the Passaic stations which we had available for modeling all lay in the more upstream and less urbanized areas of the basin. Thus there was little variation in the percent of impervious cover from station to station, and, of course, it was not able to statistically "explain" much variation in DO.

If we had more stations on the Passaic to work with, covering all phases of Passaic basin urbanization, then, we feel, the outcome would have been different, in that we believe that the impervious cover dummy variable would have performed well.

D. Results of the Simulation Runs

The final model was used to test the environmental impact of plans for the location of new disposal plants and for a secondary treatment level requirement. These findings reinforce the conclusions resulting from the Raritan study.

1. Will universal secondary treatment (a maximum effluent of 25 ppm) bring water quality levels up to the state standard for the upland Passaic? Seven of the 19 observation stations on the Passaic consistently had summer oxygen deficits throughout the simulation period. The reduction of effluent to 25 ppm improved the simulated DO levels but not nearly enough to cause them to approach the 4 ppm standard for the study area. Our conclusion is that secondary treatment alone will not have the desired effect on water quality.

2. Will centralization of treatment plants help clean up the waters? The answer to the question depends upon whether one's perspective is upstream or downstream. Four new regional plants have been proposed for the lower Pompton, the downstream portion of the upland Passaic, and at the confluence of the Whippany and Rockaway Rivers. These plants will replace 27 presently existing plants that receive more than 0.1 mgd and additional smaller disposal facilities.

Our simulations suggest that if the four regional facilities are built, six of the seven stations already suffering oxygen deficits will suffer larger deficits, while the already less polluted tributaries and upstream section of the Passaic will become even less polluted. In short, we conclude that centralization will make the clean waters cleaner and the dirty waters dirtier. This parallels our findings for the Millstone tributary of the Raritan system.

E. Conclusion

Currently accepted technological panaceas for resolving the water pollution crisis have not been sufficiently questioned. Existing data show that river and groundwater resources are experiencing pollution effects which may well be aggravated in certain areas by a centralized regional treatment plant strategy. In turn, these waters contribute pollution in ever-concentrating form to the estuaries and coastal waters of the region.

Our model suggests that -- even beyond the needed alleviation produced by the upgrading of treatment levels and prohibition of illegal effluent dumping -- urban growth may have to be reversed in some parts of our region to meet even modest pollution standards.

But our society has a deep-seated bias favoring local growth and boosterism. The most critical challenge facing environmental resource planners in an advanced industrial society may well be the design of strategies of phased retreat from overurbanization in some metropolitan areas accompanied by coordinated strategies of urban development elsewhere in order to avoid creating local situation where segments of urban society find themselves living in environments which are becoming progressively, uncontrollably, irreversibly poisoned.

APPENDIX 1

A TEST OF COMBINATIONS OF MODELS FOR PROJECTING THE POPULATION OF MINOR CIVIL DIVISIONS

The problem treated here is the projection of 567 municipal populations in the New York Metropolitan Region (NYMR) through 1985 despite the handicaps of insufficient funds and man-hours to gather data on zoning ordinances, tax pressures, birth and death rates, school enrollments, and housing permits at the minor civil division scale. The major technical difficulty was to find a means to define the probable historical-behavioral changes at a series of spatial scales, while avoiding the danger of accumulating additive errors from multiple assumptions.* The "historical-behavioral" approach differs from conventional styles of projection by emphasizing the anticipation of changes likely to alter observed trends in the growth and distribution of population. The impact of fluctuations in the fertility rate on population forecasts provide an example of the need for our approach. During the 1930s a stable or declining national population was projected by a number of curve-fitting procedures (for example, President' Research Committee on Social Trends, 1933). Writing in 1950, Dorn suggested that "the men and women who bear children refused to have their personal relationships regulated by governmental press release." (Dorn, 1950, p. 313). In fact, the unforeseen impact of increasing fertility rates made waste paper out of these estimates in a very short time. Insofar as we are able, we are attempting to devise a projection model in which the parameters may be varied to accommodate hypotheses of change.

The analyst emphasizing conventional "systematic-rigor" projection seeks to demonstrate the stability of present trends. Models are developed to measure the importance and interdependencies among an extended variabl- set including local zoning ordinances, property taxes, and the provision of public water and sewer systems. Our task of providing estimates for 567 municipalities by five-year intervals from 1970 through 1985 demands a systematic procedure. However, we hope to balance the need for a formal structure by defining appropriate spatial levels for specific historical-behavioral inserts. This appendix is divided into two parts: (1) selection of test models, and (2) test of models.

A. Selection of Test Models

The 1950 census generated a heated dialogue concerning the relative merits of a number of competing methods of estimating future population at the minor civil division scale (Schmitt 1952a, 1952b; Schmitt and Crosetti 1951, 1953; Loomer 1952; Dorn 1950; and Siegel, Shryock, and Greenberg 1954). At the municipal level and often at larger scales all methods had substantial errors -- averaging between six and 15 percent over ten years, and at least doubling if extended over two decades. One or more of the simpler extrapolative methods were usually as accurate as the more complex and data-demanding component techniques. A series of ratio extrapolations from the national level to the local level were no help.

*Meyer 1968 discusses the "historical-behavioral" and "systematic-rigor" approaches. Alonso 1968 discusses the use of simple and complex models in forecasting. He argues that complex chain models like the one tested in this paper should be used with caution because of the potential accumulation of error.

Indeed the length of the forecast was more significant than the particular methodology. The errors were traced to the failure to recognize two linked and changing behavioral patterns: a higher birth rate related in turn to increasing suburbanization.

In the intervening two decades attempts have been made to monitor and anticipate changing behavioral patterns. The federal government publishes sets of census survival and fertility rates (U.S. Bureau of Census, 1964, 1965). Steps to improve migration forecasts include greater reliance on symptomatic data (e.g., school enrollment and housing permits), land-holding capacities, regression analysis, and the introduction of more complex simulation techniques.

Symptomatic data are extremely helpful for updating census counts and methods have been devised for extrapolating them for projections (Bogue 1950, Siegel, Shryock, and Greenberg 1954, Consolidated Edison 1946, and Horowitz and Kaplan 1959). Density ceilings are useful when zoning ordinances are stable and realistic (Buffalo City Planning Commission 1949, Nash 1951, New York City, Mayor's Commission on City Planning 1940, and Notess 1966). And regression analysis is applicable if the independent variables are more easily forecasted than the dependent components, and if their relationships with the dependent variables and with one another are stable and independent (Lakshmanan 1964).

Recently, Monte Carlo and linear programming approaches have been introduced into migration research. The first has been extensively used in physics (for example, reactor research) and in the study of the diffusion of ideas and innovations; the second has been applied in economics and business. The Monte Carlo procedure assumes that migration is a random process. But rules are developed as probabilities which shape the broad pattern of migration and effectively govern the process as the number of observations increases (Hagerstrand 1957, and Morrill 1963, 1965). As the simulated population increases (e.g., from 10 to 100 to 1,000), the distribution should begin to approach the pattern implied by the probabilities.

The analyst employing linear programming attempts to optimize one or more functions which represent goals set for the system by the planner (e.g. minimize commuting time) subject to constraints (e.g., housing costs, zoning ordinances, the presence or absence of public services, social rank, life-cycle status, and local ethnic and racial composition) (Brown, Horton, and Wittick 1970, Herbert and Stevens 1960, and Ochs 1969).*

Both techniques could be useful for such problems as isolating the broad national impact of government housing and employment policies on migration. However, their applicability to a long-term projection problem at the municipal level in a large metropolitan area presently seems far-fetched. Linear programming assumes the existence of an optimizing, all-knowledgeable decision-maker, an assumption unlikely to hold even in a homogeneous society. In contrast, New York Region presents a mosaic of ethnic, racial and nationality groups. Glazer and Moynihan (1963) have

*Others have formulated migration in an input-output framework which may be converted to a linear programming problem. See, for example, Lovgren 1957 and Rogers 1968.

outlined cultural differences influencing mobility. Jews have a greater propensity for multi-unit living, while Italians prefer single or two-family residences. The Polish and Italian subpopulations are the most stable (Glazer and Moynihan 1963, Clark 1964). Puerto Ricans tend to locate between Negro and non-Puerto Rican white concentrations (Kantrowitz 1969). And Negroes tend to be the shortest distance migrants (for example, Market Planning Corporation 1959, p. 25). A programming formulation would require sets of linear (or perhaps nonlinear) objective functions and constraqnts. The author doubts whether such specifications could be achieved at any but the largest scales.

The Monte Carlo procedure seems more realistic. It requires less data and fewer assumptions. Joint probabilities would have to be defined for each potential migrant space. The probabilities might be based on a gravity formulation of accessibility to potential occupations and suitable housing for each ethnic group. The Regional Plan Association (1962, pp. 34-35) developed a gravity model to simulate intraregional population movement in the New York Region. The model included access and zoning constraints. It can be converted into a Monte Carlo formulation. However, their gravity model was developed at the county scale and its simulations even at this larger scale were less accurate than other procedures. Indeed, these more complex techniques should be tested against naive models to justify their additional data requirements and expense. The results would presumably be best in regions where accurate rules could be defined. However, simpler methods would also be more effective in such cases because historical trends would probably contain the factors defined in the rules.

Thus, in the context of our projection needs, we opted for models which were as simple as possible. In addition, symptomatic methods were not used because of data limitations and the fact that they rely on empirically-observed trends which are not explained by explicit causal mechanisms. Regression techniques were avoided owing to the causality assumption and the difficulty of forecasting such independent variables as road construction, zoning status and local employment. Two general extrapolation procedures remained: allocation of national projections and direct projection from a local base.

B. Test of the Projection Methods

The censal ratio and local extrapolative methods may be considered respectively as national and local perspective approaches (Sonnenblum 1968). The first views local growth as primarily the result of national trends, while the second focuses on local changes. Thus, they represent the analyst's view of how to introduce those factors believed to be the primary determinants of change. A number of changes at a variety of spatial levels seem likely to influence population growth and the internal distribution of residents in the study area. The five spatial levels listed below represent the scales chosen for appropriate historical-behavioral inserts: (1) National-fertility decrease, (2) Regional-region becoming a net exporter of population, (3) development ring-modification of previous suburbanization pattern, (4) county-transportation development proceeds slowly and unevenly, and (5) minor civil division-modification of zoning ordinances.

The preferred choices could not be followed for two reasons. First, the development rings are three concentric zones centered on Manhattan.* The core includes counties densely developed (an average population density greater than 30,000 per square mile) by 1940 and presently losing or stabilizing in population. Adjacent to the core are the inner and the outer rings. They are respectively less populated and further removed from lower Manhattan. A reversal of the post-Second World War tendency toward low-density, single-family developments is ideally expressed at this spatial level. Should "Spread City" (Regional Plan Association 1962) become economically infeasible or less popular, the core's share of the population could be increased at the expense of the peripheral outer ring. The concentric formulation of suburbanization, however, ignores directional biases in migration and the presence of local core cities (e.g., Bridgeport, Connecticut; New Brunswick, New Jersey) in the inner and outer rings. Therefore, potential changes in the suburbanization trend had to be inserted at both the development ring and county levels.

And second, the effect of zoning ordinances should be inserted at the minor civil division level. However, the required data were easily available only at the county scale. Accordingly, potential zoning changes were applied at the county level.

In order to accommodate and test the sensitivity of the final four potential insert levels, a set of initial projection paths were developed. The most complex was able to accommodate all of the expected changes in a series of allocations: the nation to the region, the region to the development rings, the development rings to the counties, and the counties to the minor civil divisions. Other first approaches were the allocation of national projections to minor civil divisions, and the direct projection of minor civil division populations. The projection results were compared to one another and to projections made by other groups in the region. The description of the tests proceeds from the simplest to the most complex.

1. Direct Projection of Minor Civil Division Population: Local Perspective

A randon sample of ten percent (57) of the municipalities was drawn from the population of minor civil divisions. Direct projections were developed using three methods: a geometric growth rate, a logistic, and a method developed by Newling (Newling, 1967, 1968).

The first is an exponential function of the form

$$(1)\ P_{t+m} = P_t b^m, \text{ or } P_t\ (1 + r)^m$$

*The Regional Plan Association defines the rings in 1962, 1967. An intermediate ring is also included in their definition. However, it was not in this study because most of the outer ring counties were excluded from the larger water pollution study. To achieve easy association, the remaining outer ring and intermediate ring counties were called the outer ring.

where P_t is the population at the base year t,

b is the average annual absolute increment, and

m is the time from the base year to the projection year.

It is the simplest model used. Growth rates were determined from 1940-1960 data.

A logistic of the form

$$(2)\ P_{t+m} = \frac{k}{1+e^{a+bm}}$$

where k is the asymptote,

b is a negative constant, and

e is the base of Napierian logarithms, 2.71828

was fitted to post-1920 data.* The logistic, unlike the first exponential, does not generate unbelievably high or low estimates. However, many communities in the New York Region do not presently exhibit declining growth rates or a stable population. Exurban communities tend to fit the arithmetic or geometric function, while core cities fit the quadratic exponential (Newling 1967).

Therefore, general density constraints and indications of how rapidly they would be approached were needed. Newling (1968) has developed such a methodology. He derives critical densities for urban, suburban, and rural areas in New Jersey from the following equation:

$$(3)\ d_{t+m} = A^{1/k}A - \left((1-k)^m/k \right)_{d_t} (1-k)^m$$

where A is the growth ratio when the density is one person per unit area,

k is the rate of change of the growth ratio to the rate of change of density,

d_t is the density at time t, and

$A^{1/k}$ is the critical density.

*The NYMR has been a favorite test area for exponential forms. Goodrich (in James 1929, 113-114) used a modified exponential to project the population in 1929. Pearl and Reed (in James 1929, 112-113) applied different logistics to the NYMR. A more detailed discussion may be found in Pearl and Reed 1923.

All communities classified as urban will converge at a progressively declining growth rate to the critical densities -- some by losing population, others by gaining population. Eventually, the region will reach an equilibrium of clearly defined rural, suburban, and urban densities, if unforeseen changes in the growth parameters do not occur as a result of unpredicted circumstances.

The group critical density notion was particularly applicable in the New York Region during this period. The density ceilings drastically limit population growth in most communities classified as suburban. Specifically, the vast majority of minor civil divisions defined in the study as suburban are small communities of less than four square miles that approached their present, legal holding capacities between 1950 and 1960. The critical suburban density (6,157 per square mile) limited their post-1960 growth. Moreover, suburban growth was expected to be retarded at least between 1960 and 1975 due to the increasing costs of single-family home construction and the upzoning of vacant residential land.

Upzoning appears to be a widespread practice (Regional Plan Association, 1968, 1969) aimed at excluding lower-middle to lower income families and large families. The legal mechanisms are zoning vacant acreage as half-acre or greater, single-family plots. Zoning three-room apartments (excluding large families) and assigning large parcels to nonresidential uses are also common techniques.

Newling's urban, suburban, and rural trichotomy was duplicated for the Region. However, New York City's high urban densities and the existence of extensive vacant land in the New Jersey meadowlands contributed to regression residuals in the urban equation which necessitated the use of a dummy variable. The critical densities are listed in Table 1. As yet, we have been unable to relate the empirically derived densities to any threshold density such as the development of water or sewage systems, or private and public transportation systems. The parameters A and k were determined for the four groups of counties by least squares. All minor civil divisions were then classified with respect to one of the four regression models by referring to their density in 1950 and growth rate 1950 to 1960. The density of each community was projected by substituting in equation (3) the appropriate A and k values and its population density in 1960 as the value of d_t.*

Table 1. Critical Densities for the Population of Minor Civil Divisions in the New York Region (Persons per square mile)

	Urban: Manhattan, Bronx, Brooklyn, and Queens	Other Urban or Urbanizing	Suburban or Exurban	Rural
Critical Density	41,371	12,756	6,157	527

*The author would like to thank Barry Appleman, computer center, Columbia University for programming the equations.

The projections were tested using the 1970 preliminary counts (Table 2). Newling's method was more accurate (one-tailed test at the .05 level).

Table 2. Error Level of Local Extrapolative Methods, 1970

	M o d e l		
	Newling group critical density	logistic	geometric
mean error of estimate	6.85	8.42	11.31

However, the systematic application of the density constraints seemed unnecessarily inflexible. Probable historical-behavioral changes including lowered fertility, changing inter- and intraregional migration tendencies, and increasing multi-unit construction had to be ignored. Accordingly, the ratio method was tested.

2. Ratio Extrapolation: A National Perspective

A widely used alternative to local extrapolation is the allocation of national projections directly to communities (Hagood and Siegel 1951, Goodrich 1926, White, Siegel and Rosen 1953).

$$(4)\quad P_{t+m} = \frac{P_t}{P_{a_t}} \cdot P_{a_{t+m}}$$

where P_a is the population of the larger area.

The share element $\frac{P_t}{P_{a_t}}$ is usually developed from time series data and fit by least squares or by inspection. The ratio method is the link between the national scale component methods and the local scale. The population of the locality is projected by extrapolating its shape of the larger area's population.

National projections were obtained through Census Bureau B growth rates for the periods 1960-1964 and 1976-1985. Census D rates were applied from 1965 through 1975 (U.S. Bureau of the Census 1967, 1970).* The projected 1970 population of 206.061 million is 2.7 percent above the preliminary census count and probably will be about 0.2 percent above the final count. The return to the higher B rates after 1975 rests on the following assumptions: (1) national fertility rates are closely related to the country's economic condition; (2) the present national fertility levels, which represent a near record low will increase when the economic squeeze subsides; and (3) given an economic recovery, a lag would ensue before fertility rates would rise to former levels. If the above assumptions prove to be wrong and the birth rate remains low or decreases further, the 1980 and 1985 projections will be high.

Ratios were extrapolated for the 57 communities from 1940-1960 data. The mean error of the estimate for 1970 was 9.73 percent, significantly higher than two of the three local perspective models. The errors were predictable: estimates in the inner suburbs were too high, while projections in the outer suburbs and in the core cities were too low. It was concluded that the ratio procedure could be useful only if major behavioral trends could be inserted at a series of spatial levels.

Therefore, an allocation path involving five spatial levels was developed. First the national projections were allocated to the region. The shares were based on two assumptions: (1) the pace of interregional redistribution would be retarded between 1965 and 1975; and (2) before and after this period, the region's component of the national population would decrease at post-Second World War rates. Both working rules rest on the assumption that migration is retarded by a tight economy. The assumptions seemed to have worked for the initial projection period. The 1970 projected component was 9.00 percent, the actual preliminary count was 8.98 percent.

As an added test, a single age-specific component projection was calculated using census low-fertility levels. It failed to yield results comparable to the ratio allocation until age-specific migration rates were adjusted for a decrease in interregional migration between 1965 and 1970.

Next, the regional projection was allocated to three development rings: core, inner, and outer, despite the fact that the concentric pattern masks some migration patterns involving satellite central cities not in the inner core and involves some directional biases in migration. Nevertheless, the step of adjusting estimates for the ring pattern adds a degree of regional projection control that would have been difficult to establish in a direct allocation of the national shares to counties or municipalities. Specifically, the broad regional suburbanization trend was explicitly accounted for in one step by aggregating the counties with similar historical development characteristics as defined by the Regional Plan Association (1962).

*The Census Bureau develops alternative birth rates based on an analysis of historical trends in fertility. Separate rates have been developed for the white and nonwhite populations. Series A rates yield the highest growth; Series E rates the lowest. Most plans have used B rates.

The recent history of population distribution within the region contrasts sharply with the expected trends in the near future. The densely developed core has been declining, with a precipitous decline between 1950 and 1960. The older suburbs (inner ring) have received the largest share of the absolute increment -- two-thirds between 1950 and 1960.

However, an analysis of zoning ordinances and an age-specific component projection of the inner ring's population (change in fertility levels with an older population) suggested that 90 percent of the core's relative decrease should be assigned to the outer ring. The 1970 preliminary count supported this assumption to a remarkable degree. The inner ring's share stabilized between 1960 and 1970. The net transfer was entirely between the core and outer ring.

With the major intraregional population trend accounted for, individual counties could be treated by extrapolation within the context of specific factors likely to influence them. For example, Richmond and Nassau counties' ratio extrapolations were drastically modified. Richmond's share of the inner ring population declined from 1930 to 1960. However, the Verrazano Narrows Bridge has opened the island to core migrants. Nassau County presents a contrasting picture. Its population more than tripled between 1940 and 1960. However, Nassau presently exemplifies diseconomies which resist continued migration at these levels, and which have resulted in the upzoning of vacant land, zoning against multi-unit dwellings, and high costs of housing construction.

Using zoning ordinance and housing permit records and age-specific population projections (for Nassau County), Nassau's share of the inner ring increase was reduced, while Richmond's was increased. Both estimates were supported by the 1970 preliminary census count in which Richmond's share of the inner ring population substantially increased, while Nassau's share stabilized.

Recapitulating, county projections were developed in a series of steps -- national to regional, regional to development rings, and development rings to counties. The estimates were tested and were found to be more accurate than both published projections and the summed county estimates derived from applying Newling's method in the region's 567 municipalities.

Table 3. Error Level of Alternative Methods, County Scale, 1970

	Model				
	Five-Step Allocation Path	Newling Method	New York Port Authority*	Regional Plan Association** (22 counties)	New Jersey Council of Economic Development*** (10 counties)
Mean Error of Estimate	3.64	4.78	7.46	8.11	7.61

Source: *Port Authority of New York, The Next Twenty Years, New York: 1966, pp. 6-7.

**Regional Plan Association, Spread City, Bulletin 100, New York: Regional Plan Association, 1962, p. 36.

***New Jersey Dept. of Conservation and Economic Development in Commission on Efficiency and Economy in State Government, Water Resources Management in New Jersey, Trenton: 1967, p. 24.

Seven counties had deviations greater than four percent. Two sources of error were identified. First, the national estimate was 2.7 percent above the preliminary census count, despite the use of the lower Census D rates between 1965 and 1970. This deviation was carried through the regional and subregional levels to the counties. However, the final census count should be within 0.2 percent of the projection, all but removing this error component. A second major error source can be isolated if the first difference is held constant: overestimation in the inner ring, underestimation in the outer ring. While the focus of migration was expected to shift from the inner to the outer suburbs, the estimate was imperfect. Compensatory steps can be taken to correct this difference at the development ring scale. A more costly, but more precise procedure would require estimating directional biases in migration and adjusting each migration path separately, through the acquisition of a large mass of additional data.

As an additional check, single total component projections were made for five of the 23 counties. Once again, the more complex model yielded inferior results unless adjusted to the behavioral trends.

Finally, ratios were allocated from the counties to the 57 sample communities. The mean error of the estimate was 7.01 percent, above the projections developed from Newling's local perspective model. Thus, the modified ratio model was superior at the county scale, the critical density model at the minor civil division scale.

3. A Combination of National and Local Perspective Models

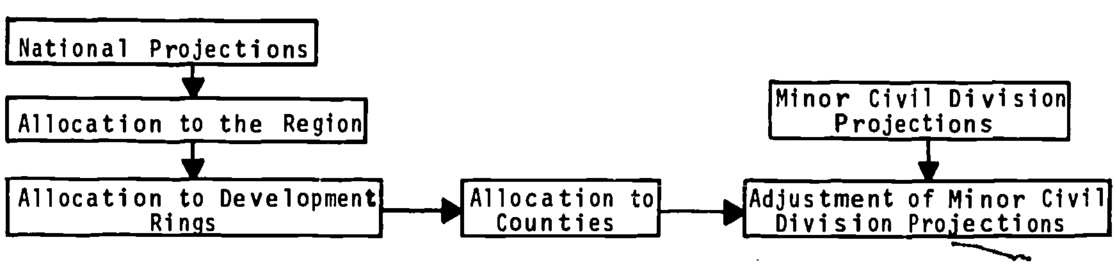
An analysis of the residuals from the five-step ratio extrapolation indicated that the final set of allocations contained larger errors because of the failure to adjust within the county for the changing suburbanization pattern. Therefore, it was decided to combine the censal ratio and local extrapolative methods. The first was used to constrain the second. The difference between the two sets of county projections was determined. The increment from the ratio method was added or subtracted in the following manner: (1) each community's share of its county population in the previous time period was calculated (1960 for 1970, 1970 for 1975,...) and (2) the difference was assigned or removed according to the percentage calculated in the first step. The justification for this procedure is the presence and likely construction of high-rise apartments in the more populous cities. A better alternative would have been to apply holding capacities of vacant land or of land likely to be developed in the study period. However, such data were not available at the minor civil division scale.

The combined procedures yielded more accurate results. The mean error of adjusted local projections was 5.3 percent, significantly better than the previous best estimate of 6.85 (on Table 2). Moreover, the combination should become more potent during the study period as the national perspective portion constrains the estimates derived from the inflexible local perspective model.

Conclusion

Figure 1 depicts the most complex and accurate projection path. National projections were calculated and allocated to the region. These estimates were, in turn, allocated to development rings, and thence to counties. Minor civil division projections were developed independently. County projections from the censal ratio and local perspective methods were compared. The first were used to adjust the second.

Figure 1. Flow Diagram of Projection Steps



This complex path should be judged from two perspectives: cost and accuracy. The number of man-hours involved in structuring the combined procedures was more than three times that required to develop the local perspective equations. Whether the added cost is worth the difference in accuracy will vary with the individual project. In the case of this study, the added accuracy must be evaluated in terms of its use, which involves multiplying the population projections by per-capita effluent discharge coefficients derived from much weaker data sources. Thus, on the one hand, the population projection accuracy is blunted by the errors in the effluent coefficients. On the other hand we avoid the additional multiplicative error which would be introduced by forming the product of two numbers, both of which have inaccuracies.

While the combination of methods proved to be more accurate than any of the simpler procedures in 1970, the long-term projections generated by this study depend upon the condition that present economic conditions and their ramifications improve between 1975 and 1985. Indeed, the flexibility required to introduce trends at five spatial levels could prove to be disadvantageous by the end of the study period. The multi-level inserts into the ratio extrapolations involve a hierarchy of assumptions which could make it difficult to isolate sources of error due to spatial autocorrelation effects. If, however, the economy recovers, if zoning ordinances can be bent, if not broken, and if a program of high-rise construction begins by the latter portion of the 1970s, the projections from the combined methods should certainly continue to be more accurate than any of the alternatives. Present tendencies suggest that this will be so. Critical zoning cases are already in the courts, and public policy aimed at the diffusion of high rise construction outward is already under formulation.

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APPENDIX 2

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B 1.8	Griffith, C. Coleman and Rodevick, Michael L., "BOD from Poultry Processing Plants," Purdue University Industrial Waste Conference Proceedings, Engineering Extension Series #135, Part 1, (May 1969), p. 713.	2015

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		202-dairy products
B 2.1	Dlouhy, P.E. and Dahlstrom, "Food and Fermentation Waste Disposal," Chemical Engineering Prog., (January 1969), 65, pp. 52-7.	2022 cheese-nat.&proc. 2026 fluid milk
B 2.2	Federal Water Pollution Control Administration, U.S. Department of the Interior, "The Cost of Clean Water," Vol. 3, Industrial Waste Profile Series #9, "Dairies," U.S. Government Printing Office, Washington D.C.: June 1967.	2021 to 2026 2021 creamery butter 2023 condensed and evaporated milk 2024 ice cream and frozen deserts 2025 eliminated by census
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B 3.15	Borchardt, Jack A. and Pohland, Fred G., "Anaerobic Treatment of Alewife Processing Wastes," WPCFJ, (December, 1970), p. 2060.	2036	fresh or frozen packaged fish
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B 8.8	Dlouhy, P.E. and Dahlstrom, "Food and Fermentation Waste Disposal," Chem. Eng. Prog., 65: (January 1969), pp. 52-7	2082 2084 2086

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B 9.2	Londong, Dieter, "Purification of Wastes from a German Yeast Plant," Purdue University Industrial Waste Conference Proceedings, Engineering Extension Series #135, Part 1, (May 1969), p. 770.	2099 food preparations, NEC
B 10.1	Federal Water Pollution Control Administration, U.S. Department of the Interior, "The Cost of Clean Water," Vol. 3, Indistrial Waste Profile Series #4, "Textile Mill Products," U.S. Gov't Printing Office, Washington, D.C.: June 1967.	2231 weaving and finishing mills, wool 2261 finishing plants, cotton 2262 finishing plants, synthetics
B 10.2	Masselli, Joseph W., Masselli, Nicholas W., and Burford, M. Gilbert, "A Simplification of Textile Waste Survey and Treatment," New England Interstate Water Pollution Control Commission, Boston, Mass.: July 1959.	2231 226 textile finishing except wool
B 10.3	Schlesinger, Herbert A., Dul, Emil F., Fridy, Thomas A. Fr., "Pollution Control in Textile Mills," in Herbert Lund, ed. Industrial Water Pollution Control Handbook, McGraw Hill Book Co., N.Y.: 1971.	2231 226
B 10.4	Smith, Arthur L., "Waste Disposal by Textile Plants," WPCFJ, (November 1965), p. 1607.	226
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B 11.7	El-Dib, M.A. and Ramadan, F.M., "Characterization of Starch, Paperboard and Gelatin Wastes," WPCFJ (January 1966), p. 46.	2631 paperboard mills
B 11.8	Bamman, R.K., "Papermaking, Coating and Decoating Waste Treatment Plant at the Ohio Division, Champion Papers, Inc.," Purdue University Industrial Waste Conference Proceedings, Engineering Extension Series #112, (May 1962), p. 53.	2641 paper coating and glazing
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B 12.1	Gaydos, J.G. and Rogers, A.N., "Pollution Control can be Profitable," <u>Water and Wastes Eng.</u>, Vol. 6, (November 1969), p. F 14-15.	281 industrial chemicals
B 12.2	Granstrom, M.L., Dutta, M., DeRooy, J., "Water Resources and the Chemical Industry in New Jersey--An Econometric and Engineering Analysis," New Jersey Water Resources Research Institute, Rutgers--The State University, New Brunswick, N.J.: October 1969.	28 chemicals and allied products
B 12.3	Parrott, J.W. and Smith, W.M., "Water Pollution Control at the Rohm and Haas Houston Plant," Water and Sewage Works, (January 1971), p. IW 4.	2818 industrial organic chemicals, NEC
B 12.4	Schneider, Robert Jr., "The Lake Michigan Enforcement Conference," Purdue University <u>Industrial Waste Conference Proceedings, Engineering Extension Series #132, Part 2,</u> (May 1968), p. 978.	281
B 12.6	Rice, Cyrus William and Co., "Projected Wastewater Treatment Costs in the Organic Chemicals Industry," prepared under contract for the FWPCA, Dept. of the Interior, Washington, D.C.: 1968.	2815 cyclic intermediates and crudes 2818
B 12.7	Bess, F.D. and Conway, R.A. "Aerated Stabilization of Synthetic Organic Chemical Wastes," <u>WPCFJ</u>, (June 1966), p. 939.	2818
B 12.8	Bramer, Henry and Gurnham, C. Fred, "Projected Wastewater Treatment Costs in the Organic Chemicals Industry," Purdue University <u>Industrial Waste Conference Proceedings, Engineering Extension Series #135, Part 2,</u> (May 1969), p. 979.	2818
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APPENDIX 3

INDUSTRIAL WASTE COEFFICIENTS
BY FOUR DIGIT SIC CATEGORIES

SIC	Flow (gal.) per unit Production	BOD	SS	Grease	COD	Total Diss. Solids	Total Solids	Alk.	Acid.
2621*	25,000- 84,000	285-404	271-431			1155-1648	1426-2007		
2631	17,500-103,000	393-1022			293-605				
2640	1437	250-300	1250						
2812	14,542	10	186		465	323	5417	80	
		Phenol:36	Chlorides: 1045						
2815	642-4231 (4)	303-1986	13	89	873-4519		3619	527	
		Phenol:18							
2818	418-3472 (4)	355-2645	600	89	804-5170		3121	2314	
		Phenol: 9							
2819	3928	230			581				
2821	13.2	245							
2822	12-400	63							
2823	141	304							
2824	61.8	111							
2834	153	383	96		767				
2841	0.3-2.8	499	439		449				
2851	10.34	96	72						
2861	11543.21	449	200		315				
2891	5.45	1089	31						

*SIC Numbers refer to categories set forth in Appendix 2.

SIC	Flow (gal.) per unit Production	BOD	SS	Grease	COD	Total Diss. Solids	Total Solids	Alk.	Acid.
2892	142	44							
2899	4,938	327		53			129		
2911	18-1400	(5) 6.6-385	0.7-106	5-65	20-700	200-4933			
		Phenol:0.02-110 S:0.3-40 P:0.5-13.4 NH_3-N:5.7-40						5-285	
	50-250	120-192	22-42	7-35	43-62				
		Phenol:4-14 S:5-22							
3111	5-10.5	1049-2397	1258-4817						
		S:62-192 Cr:30-120 VS:749-2564 Hardness:1003-2564 Protein:629-1606					3775-12,846	NH_3-N:37-96	
3312	9860-13000		1203-1686						
		Tin: 0.12 $FeCl_2$:19.3 HCl:5.2							
		Lube Oils: 22-37 NH_3-N:0.72-0.96 H_2SO_4:26-43 Cr:0.48-0.72							
		$FeSO_4$:97-160 CN:0.24-0.36 F:D.24-0.36							

APPENDIX 4

INDUSTRIAL PRODUCTION ESTIMATION FOR REGIONAL PRODUCTION OUTPUT IN SIC CATEGORIES WHICH ARE POTENTIAL POLLUTERS

Regional estimates were developed by modifying the shift-share technique. The implicit share component has recently been questioned (Brown, 1969 and Houston, 1967). As a result the author tested the shift-share approach against three variant models: (1) a constant share model, (2) simple time series extrapolations, and (3) a model incorporating population as the competitive component. The last model usually proved to be the most accurate when front- and backfitted to census data.

The 42 industries were classified into market- and supply-oriented groups. Final projections for the ten local market-oriented industries were developed from the following model.*

$$(4)\quad O_{i,\ NYR_{t+m}} = \frac{P_{NYR_{t+m-1}}}{P_{US_{t+m-1}}} \cdot O_{i,US_{t+m}} ,$$

where O is the output,

i is the ith industry.

NYR is the New York region,

US is the United States,

t is the base period,

m is the temporal increment.

Regional production of supply-oriented manufacturers was simulated by a population-weighted constant share model.

$$(5)\quad O_{i,\ NYR_{t+m}} = \frac{O_{i,\ NYR_t}}{O_{i,\ US_t}} \cdot O_{i,\ US_{t+m}} \cdot \frac{P_{NYR_{t+m-1}}}{P_{US_{t+m-1}}} \bigg/ \frac{P_{NYR_{t-1}}}{P_{US_{t-1}}}$$

A direct allocation of the regional projections to the plants would have overlooked the intrametropolitan movements of industry. Noxious industries were among the first groups to leave the densely developed areas. Presently, more than half of the regional production of the seven two-digit groups

*The market model was developed by Daryl Hellman. See Daryl Hellman and M. Marcus, 1970.

listed in Table 5, page , occurs in six New Jersey counties which contain less than one-fourth of the region's population.* Concentration of heavy industries in this area has steadily increased since the turn of the century.

Accordingly, an attempt was made to describe and to model the intra-metropolitan movement of the 42 industries. The disclosure rule confined the analysis to the seven two-digit industrial groups. The following set of general hypotheses was operationalized and tested at the county scale: (1) search for suburban space and market; (2) search for zoned industrial space; and (3) search for economies of urbanization.

Suitable regression results were obtained for four of the seven industrial groups. Two are included for the reader's observation: food (20) and paper (26).

$$\text{(6a)} \quad Y20_{i_{t+m}} = .7678 - .0491\, PD_{i_{t+m}} - .555W_{i_{t+m}} \quad (r^2 = .593)$$

$$\text{(6b)} \quad Y26_{i_{t+m}} = .1480 - .0419\, PD_{i_{t+m}} - 1.480PR_{i_{t+m}} + 1.429W_{i_{t+m}} \quad (r^2 = .801)$$

where Y = relative change in production

i = county i, where $i = 1,2, \ldots 23$

t = base year, 1970

m = 5 year increments through 1985

PD = population density in 1000s

W = presence of water and sewer service

PR = presence of port and rail service

The four intraregional regression models could not be used until it could be adequately demonstrated that the two-digit groups represented the spatial patterns of the three- and the four-digit groups. Overall, only 18 of the 42 industries were fitted with an intraregional shift component. It was implemented by calculating a table of relative change coefficient. Each element in the table of preliminary estimates made via the constant share approach was multiplied by its unique expected intraregional change

*The counties are Bergen, Essex, Hudson, Middlesex, Passaic and Union.

coefficient. Thus, the redistribution of production within the region was accommodated by changing the output of already existing plants, rather than by adding or subtracting plants.

The allocation of production estimates proved to be a cumbersome and a frustrating task. The only body of plant data came from directories which listed employment, location and SIC codes. The directories were clearly not comprehensive, since known major plants were missing. Inevitable conflicts were present when plants produced multiple products. The problem was exacerbated because effluent coefficients were developed per unit of product. Accordingly, it was necessary to decide the extent to which particular effluents characterized any given plant. Another problem was that the directories often did not separate production and office employment. Finally, employment may not always be related to production. An older plant with more employees but with older processes and equipment might produce less than a newer, more mechanized plant.

The plant data from the directories were summed and compared to county and regional totals from the census. The results varied considerably, but systematically. One amusing case of error in the directories arose from the assignment of national employment totals to the region by a national headquarters located in Manhattan (who should have known local conditions better). Overall, the median difference between the 1967 census and 1970 directory data was 18 percent.

By these means, single production estimates were developed for each of the 2,026 plants and for each of the four projection years. These estimates signal a substantial increase in industrial pollution if present production techniques are continued.

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